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INVESTIGATION OF SITE COVERAGE AND ASSOCIATED PROBLEMS AT THE O'HARE AIRPORT, CHICAGO, ILLINOIS, ENROUTE RADAR BEACON TEST SITE

George F. Spingler

APRIL 1973

INTERIM REPORT

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16. Abstract

A temporary beacon test site was installed adjacent to the Chicago, Illinois, O'Hare Airport and operational tests were conducted to determine its suitability for possible use as a future enroute radar beacon site. Photographic data were collected using "targets-of-opportunity" flying within the coverage area of the test site. The data were analyzed at NAFEC to determine the extent of the radar beacon coverage and further scrutinized to uncover any anomolies which might derogate the operation of an enroute radar beacon site installed at the test location. As a result of the initial data analysis, flight tests were conducted in the vicinity of the O'Hare Enroute Radar Beacon Test Site using a NAFEC jet aircraft. The NAFEC flight tests confirmed the originally-suspected problem areas and provided additional justification for linking the anomolies to the vertical radiation pattern of the standard radar beacon directional antenna. The total test effort showed that: (1) the procedure of using a temporary beacon test facility to determine coverage and problem area of future radar beacon sites was sound, and (2) that this procedure should be utilized whenever there is some question about the adequacy of the coverage that a future site might provide.

17. Key Words
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PREFACE

I wish to express my appreciation to my associates from the Great Lakes Region who participated in the testing of the O'Hare Airport Enroute Radar Beacon Test Site.

I also wish to thank Air Traffic Controllers Robert J. Lucas, (NAFEC), Duane L. Johnson (NAFEC), and Joseph Chaloka (Great Lakes Region); pilots Kenneth B. Johnson, Jesse S. Terry, and Fredrick G. Auer; photographers John J. Bradley and James P. McGrail; engineer Barry J. Saltzman; and technicians Stanley L. Scull and Joseph H. Reed for their much needed assistance.

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INTRODUCTION

PURPOSE.

The purpose of this effort was to conduct tests in the vicinity of the Chicago O'Hare Airport to determine the suitability of a test site location for possible use as a future enroute radar beacon site. The coverage (within 150 miles) of the O'Hare Airport Radar Beacon Test Site was investigated as well as any problems which might derogate the operation of an enroute radar beacon site installed at the test location in the future.

BACKGROUND.

In August 1971, the Central Region of the Federal Aviation Administration (FAA) requested that the National Aviation Facilities Experimental Center (NAFEC) participate in an investigation of reflected radar beacon replies at the McCook Enroute Radar Site. Flight tests were conducted within the coverage area of the McCook Site using a NAFEC aircraft. The result of the flight tests indicated that the occurrence of reflected replies from nearby buildings was so extensive that the reflected reply problem could not be resolved unless the site was relocated.

The Central Region had been looking for a new site for the McCook Enroute Radar Site prior to the NAFEC investigation and this effort was continued when the Central Region, in early 1972, turned over the responsibility for the McCook Enroute Radar Site to the Great Lakes Region.

The beacon test site property, owned by the city of Chicago (see Figure 1), was located adjacent to the runway complex of the O'Hare Airport. The property is presently being used as an agricultural nursery.

Operational tests were conducted at the O'Hare Airport Radar Beacon Test Site (beacon test site) using targets-of-opportunity, flight inspection aircraft, and a NAFEC aircraft. The result of these tests are documented herein.

DESCRIPTION OF SITE EQUIPMENT.

In order to simulate a radar beacon directional antenna installed on a conventional 50-foot enroute radar tower, a 70-foot tower was fabricated at the test site using typical construction scaffolding (see Figure 2). Since the tests were conducted at radar beacon frequencies only, an enroute radar antenna was not required. The Air Traffic Control Beacon Interrogator (ATCBI) Directional Antenna, Type FA-8043, was mounted directly on top of the scaffolding tower on an Antenna Pedestal, Type AB-294/FPS-8.

An omnidirectional antenna was also installed at the test site so that Improved 3-Pulse Side Lobe Suppression (SLS) could be implemented. The Ommnidirectional Antenna, Type FA-8044, was installed on the tower so that the bottom of the omnidirectional antenna was at the same vertical height as

FIGURE 1. AERIAL PHOTOGRAPH SHOWING RELATIONSHIP OF THE BEACON TEST SITE OF THE O'HARE AIRPORT

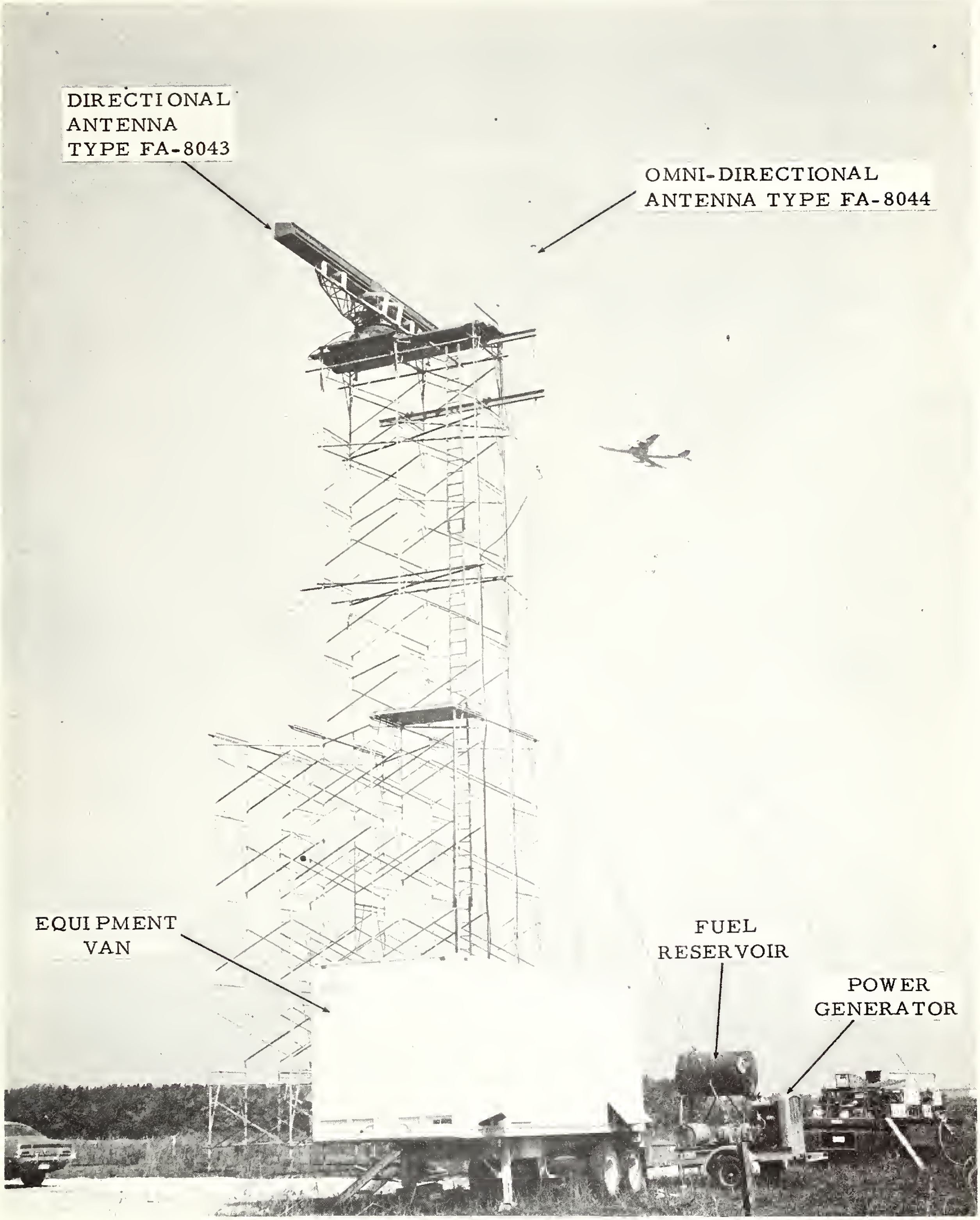


FIGURE 2. LAYOUT OF BEACON TEST SITE SHOWING TEMPORARY TOWER AND EQUIPMENT

the top of the directional antenna. The omnidirectional antenna was also installed so that the centers of the omnidirectional and directional antennas were separated in the horizontal plane by approximately 15 feet.

An equipment van (26' x 8') was used at the test site to house the radar beacon interrogator, defruiter, decoder and indicator equipment. Power for all of the test site equipment was supplied by a 25KVA 3-phase 110/208 volts Portable Generator (see Figure 2). The mobile van, with its equipment, the antenna pedestal and the antennas were all part of a Mobile Enroute Radar Facility (MERF) loaned to the Great Lakes Region by the Aeronautical Center, Oklahoma City, Oklahoma, to implement the beacon test site.

The radar beacon equipment installed in the mobile equipment van was used to provide a video display for observation by an air traffic controller and simultaneously photographed for future reduction and analysis of data (see Figure 3). The main and standby interrogators were Air Traffic Control Beacon Interrogators, Model ATCBI-4. The Model ATCBI-4 interrogators provided the normal, Mode 3/A only, beacon interrogator functions as well as improved 3-pulse SLS operation. Removal of non-synchronous radar beacon replies resulting from other interrogators was accomplished by utilizing an Interference Blanker, Type MX-8757/UPX, on both the main and standby channels.

Decoding of the interrogator output was performed within the mobile equipment van by the main or standby Common (Decoder) Rack, Type FA-6193. Selection of the video that was displayed on the Console Cabinet, Type CA-4080A (ARSR-1 display), was controlled by a Master Control Box (10-Channel), Type FA-6191A.

DISCUSSION

GENERAL.

Prior to conducting coverage tests at the beacon test site, the interrogation mode of the ATCBI-4 interrogators was set for Mode 3/A only and the pulse repetition frequency (PRF) of the interrogators was set for 350 interrogations per second. The pulse parameters of both interrogators were also adjusted so they met the U. S. National Aviation Standard for the Mark X (SIF) Air Traffic Control Radar Beacon System (ATCRBS) characteristics.

The average pulse power for two pulses was measured on the directional antenna transmission line at the transmitter and at the directional antenna to determine the attenuation afforded the radar beacon interrogations by the transmission line. The average power at the transmitter measured 8.4 milliwatts (mw) through 20dB of additional attenuation (1,500 watts peak power), while the average power at the directional antenna measured 1.4 mw through the same 20dB of additional attenuation (250 watts peak power). This difference in power indicated that the RG-8U coaxial cable, RG-218U coaxial cable, and pedestal rotary joint attenuated the radar beacon directional antenna signal by 7.78dB.

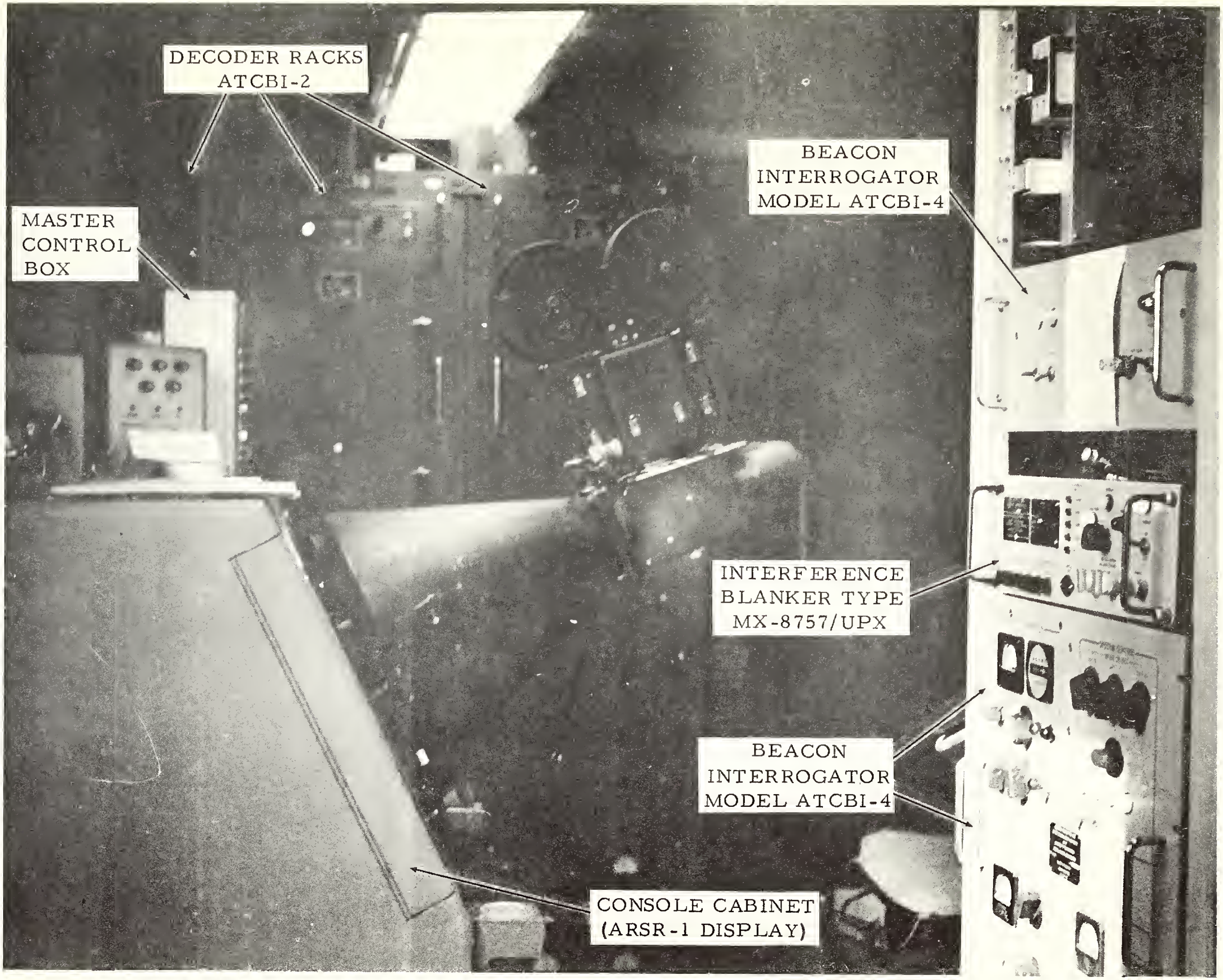


FIGURE 3. EQUIPMENT LAYOUT AS INSTALLED INSIDE THE EQUIPMENT VAN

Receiver tangential sensitivity measurements were made on both channels of the ATCBI-4 interrogator and the Sensitivity Time Control (STC) curve was set to 36dB attenuation on each receiver.

The measurements were as follows:

Channel 1.

Receiver tangential sensitivity: -88.8dBm

STC curve readings:

Delay (μs)	Attenuation(dB)	Reduced Receiver Sensitivity (-dBm)
15	36.0*	52.8
27	30.6	58.2
52	25.0	63.8
102	19.0	69.8
200	12.8	76.0
398	6.7	82.1
794	0	88.8

Channel 2.

Receiver tangential sensitivity: -87.6dBm

STC curve readings:

Delay (μs)	Attenuation (dB)	Reduced Receiver Sensitivity (-dBm)
15	36.2*	51.4
27	30.0	57.6
52	24.0	63.6
102	18.0	69.6
200	11.5	76.1
398	5.5	82.1
794	0	87.6

*The dB attenuation at 15 μs delay designates the value of the STC curve.

Measurements were made of the radar beacon system overall sensitivity by determining the minimum signal at the receiver input that would be displayed on the ARSR-1 Plan Position Indicator (PPI) display. In this manner, the effects of the receiver, interference blanker (defruiter), decoder and display circuitry were all taken into account. The minimum receiver input signal that was displayed on the ARSR-1 dPI Display measured -83dBm on both the main and standby channels.

DESCRIPTION OF FLIGHT TESTS.

Three types of flight tests were performed during September and October 1972, to determine the radar beacon coverage of the beacon test site. They were:

1. Targets-of-opportunity,
2. Flight Inspection District Office (FIDO) high- and low-altitude aircraft flight tests, and
3. NAFEC aircraft flight tests.

All of the flight tests were observed by an air traffic controller from either the Great Lakes Region or NAFEC. The 35 mm camera (Figure 3) that was mounted on the ARSR-1 PPI display contained a semi-transparent, periscope-type mirror which allowed simultaneous viewing of the PPI display by the air traffic controller and recording of data by the camera. During all of the flight tests, the air traffic controllers recorded any unusual occurrences; e.g., loss of replies, reflected replies or change of altitude.

TARGETS-OF-OPPORTUNITY.

The major portion of the targets-of-opportunity were recorded on Friday, 15 September, and Friday, 22 September, between the hours of 1500 and 2000 hours. This is the time when the traffic reaches a maximum in the Chicago O'Hare Airport area. The high level of air traffic during these times provided a complete but random coverage of all portions of the airways within the beacon test site coverage area.

FIDO AIRCRAFT FLIGHT TESTS.

HIGH-ALTITUDE FLIGHT TESTS. High-altitude flight tests of the beacon test site were conducted using a FIDO aircraft on 20 September 1972, between 1400 and 1800 hours. An Aero Commander, Type AC21, was flown to the area from Oklahoma City, Oklahoma, for this purpose. The route of the flight tests are shown in Figure 4 along with any pertinent flight test information. The test was broken into two segments to allow the aircraft to replenish the fuel that was consumed on the flight from Oklahoma City. The segmenting of the flight test allowed the aircraft to enter the test area at an altitude of 29,000 feet (FL 290), but also caused an interruption in the high-altitude testing in the area of Green Bay, Wisconsin.

From Figure 4, it can be seen that the initial portion of the flight test commenced over the Capital VORTAC and ended in Green Bay, where the pilot landed the aircraft to refuel. The major portion of this leg of the flight test was flown at 26,000 feet (FL 260) until the pilot descended the aircraft to land at Green Bay.

After refueling, the pilot climbed the aircraft to 27,000 feet (FL 270) where it remained until the end of the flight test. The pilot diverted the aircraft over the Wheatland Intersection from its intended course, the 175° radial of the Northbrook VORTAC, to the Woodland Intersection. The diversion

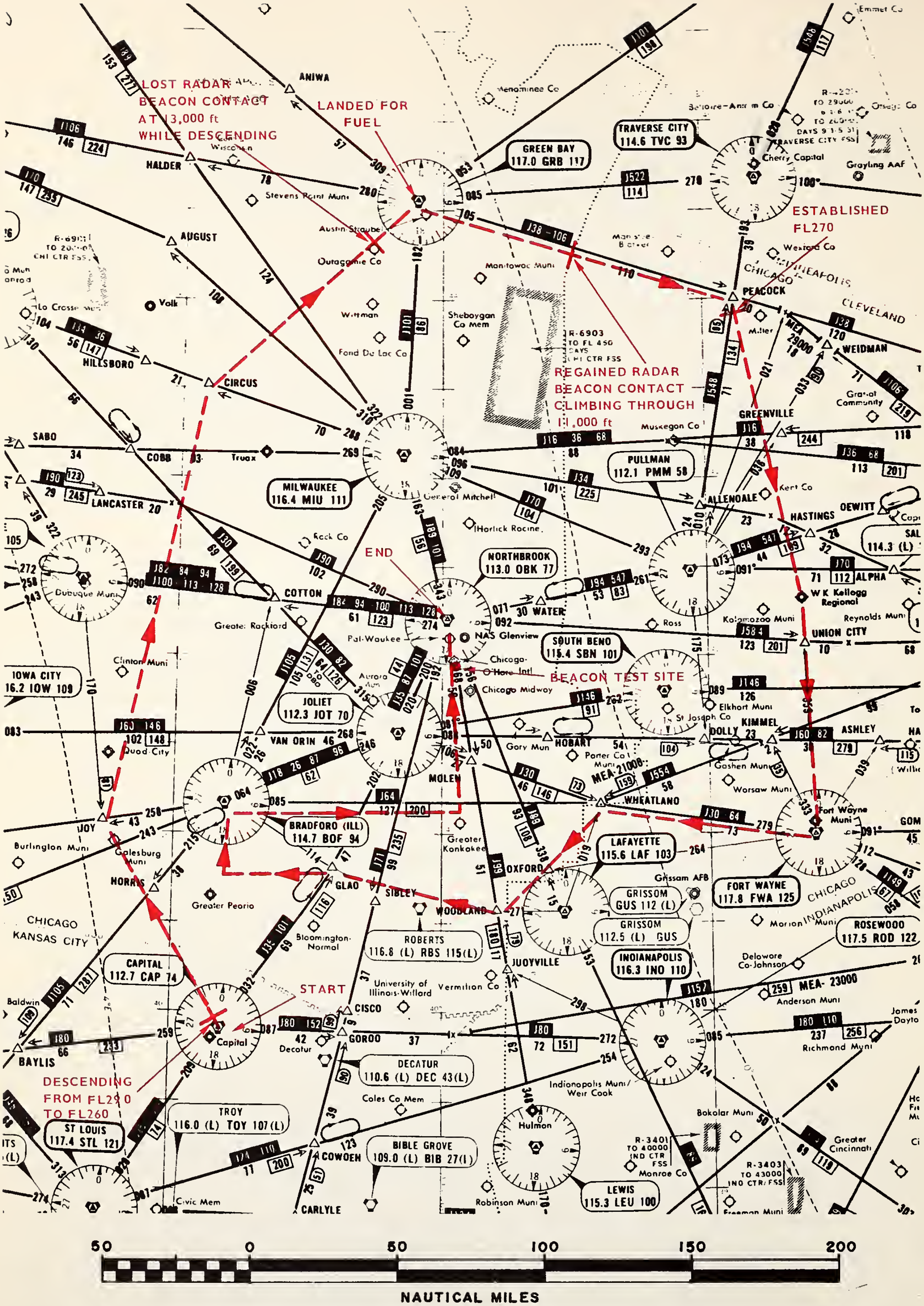


FIGURE 4. FLIGHT PATH OF FIDO HIGH-ALTITUDE FLIGHT TEST

allowed for a more complete high-altitude flight test coverage while still allowing a sufficient reserve of fuel to land the aircraft at the W.K. Kellogg Airport in Battle Creek, Michigan, after the flight test was completed. Prior to ending the tests, the aircraft was flown over the beacon test site so that the overhead coverage could be measured at 27,000 feet (FL 270).

LOW-ALTITUDE FLIGHT TEST. Low-altitude flight tests of the beacon test site were conducted using a FIDO aircraft on 21 and 22 September 1972. A Douglas DC-3 aircraft was flown to the area from Battle Creek, Michigan, for this purpose. The low-altitude flight tests were so extensive that 2 days were required to complete the testing. A morning and afternoon flight test was conducted on 21 September, and a morning flight test was required on 22 September. The routes of the flight tests are shown in Figures 5, 6, and 7 along with the flight test altitude of each path. The figures are presented in a chronological order starting with the morning of 21 September.

All of the low-altitude flight tests were made at altitudes between 2,500 and 5,000 feet. One segment of the flight test, during the morning of 21 September, extended to a maximum range of 62 nmi from the beacon test site. This occurred over the Vermillion Intersection where a change in altitude from 4,000 feet to 2,500 feet was also requested. The descent maneuver combined with the extreme range was made to determine the minimum coverage in this area.

Before the FIDO aircraft completed the flight test on the morning of 21 September, the aircraft was landed at the O'Hare Airport for fuel. After refueling, the flight test was continued until lunch time. A beacon test site overhead-flight was included as part of the afternoon low-altitude flight tests on 21 September.

During the flight tests on the morning of 22 September, the improved 3-pulse SLS was turned off. This occurred when the aircraft was in the vicinity of the Crib Intersection, and was done to determine whether the improved 3-pulse SLS had caused any loss of replies or changes in the system operation. The FIDO flight test aircraft was also diverted during the morning flight test in the vicinity of the Chicago Heights VORTAC. The pilot was concerned about the operation of some of the aircraft's equipment and placed the aircraft in a holding pattern while he requested maintenance consultation.

NAFEC AIRCRAFT FLIGHT TESTS.

The flight tests that were conducted at the radar beacon test site, utilizing a NAFEC aircraft, were made during the week of 2 October 1972. A Convair 880 M Jet Aircraft (FAA N-112) (see Figure 8) was used to verify problem areas uncovered during the analysis of the targets-of-opportunity data and the FIDO flight test data. The analysis of the targets-of-opportunity data and the FIDO flight test data took place during the week of 25 September.

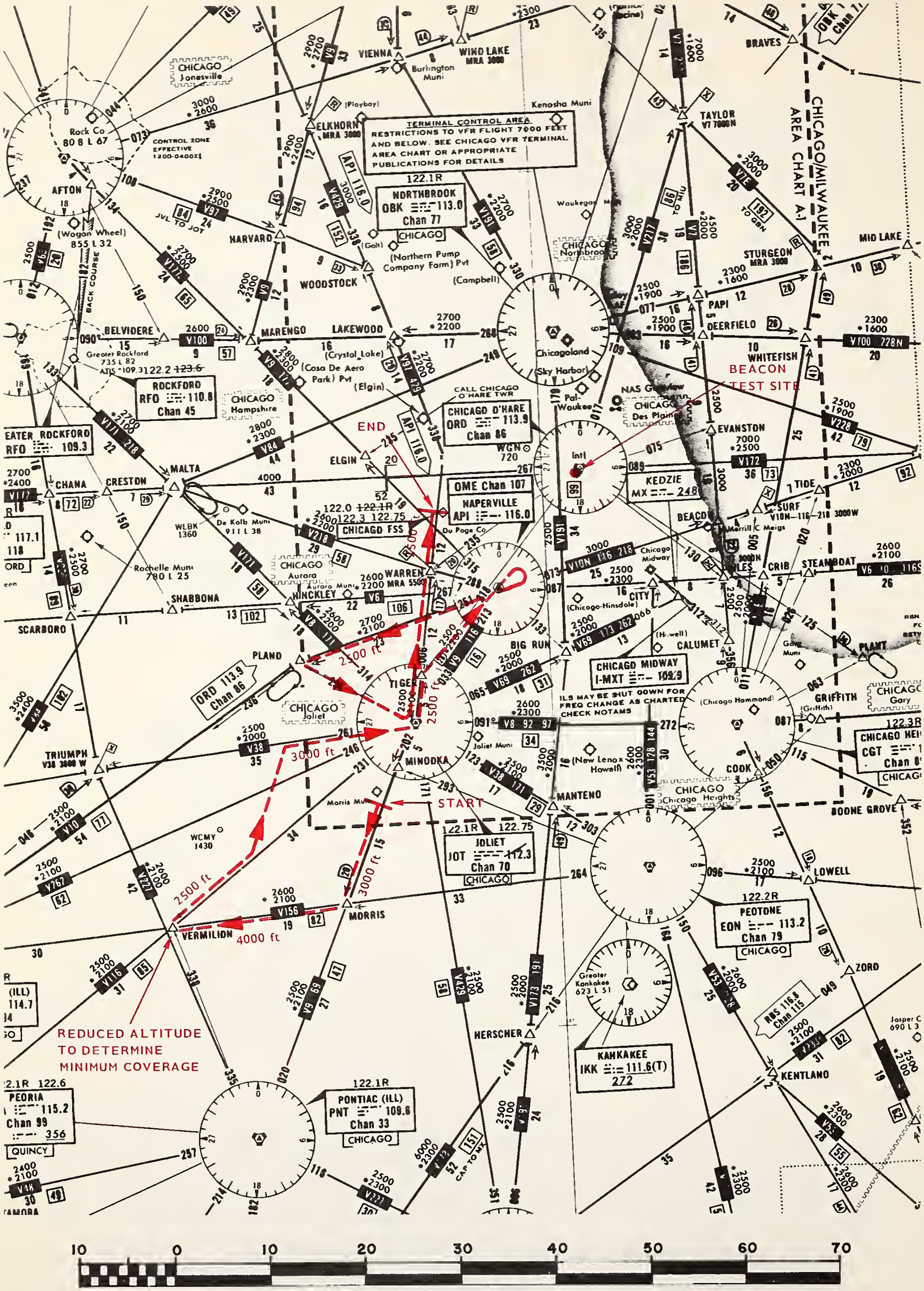


FIGURE 5. FLIGHT PATH OF FIDO LOW-ALTITUDE FLIGHT TEST CONDUCTED 21 SEPTEMBER IN THE MORNING

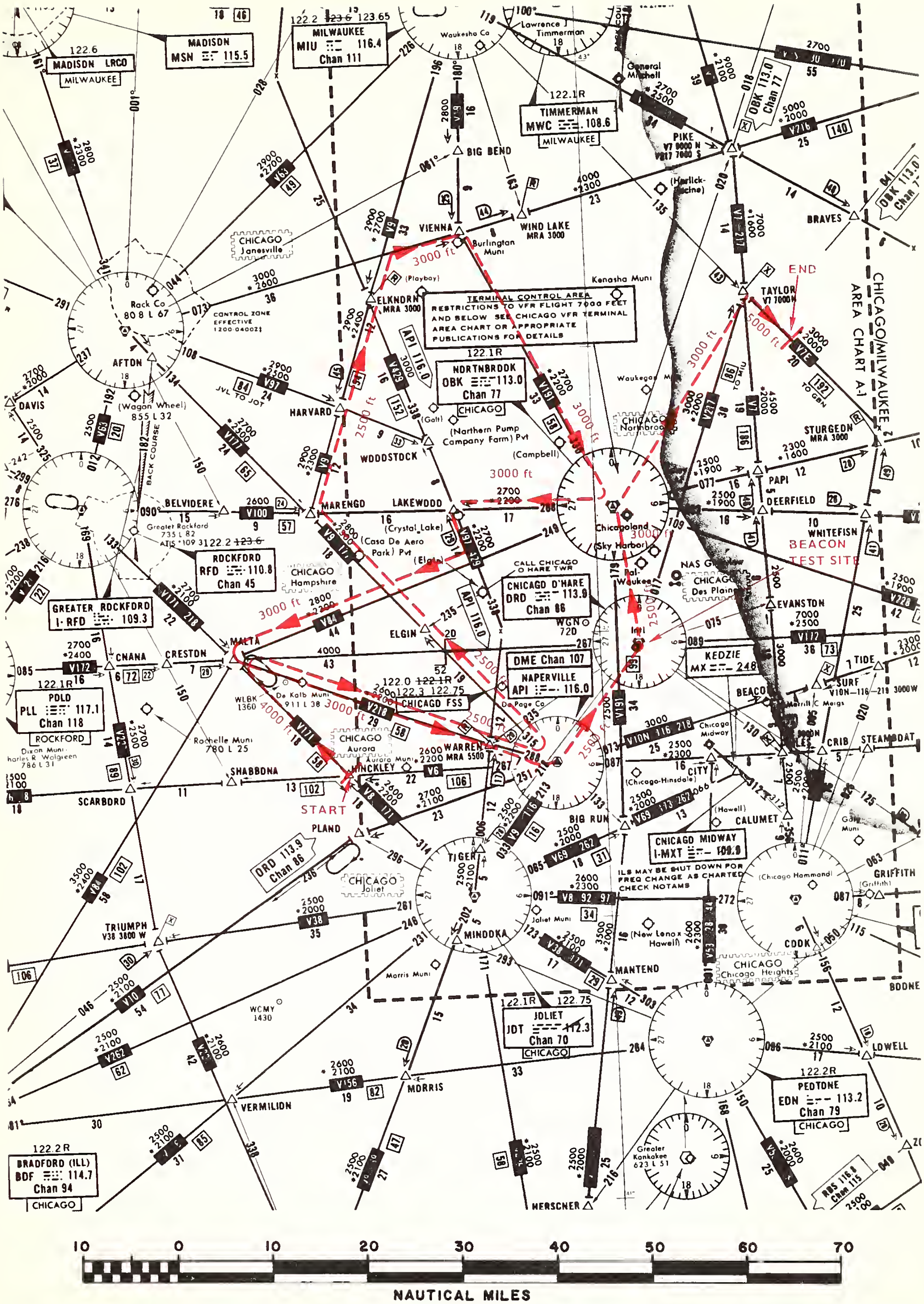


FIGURE 6. FLIGHT PATH OF FIDO LOW-ALTITUDE FLIGHT TEST CONDUCTED 21 SEPTEMBER IN THE AFTERNOON

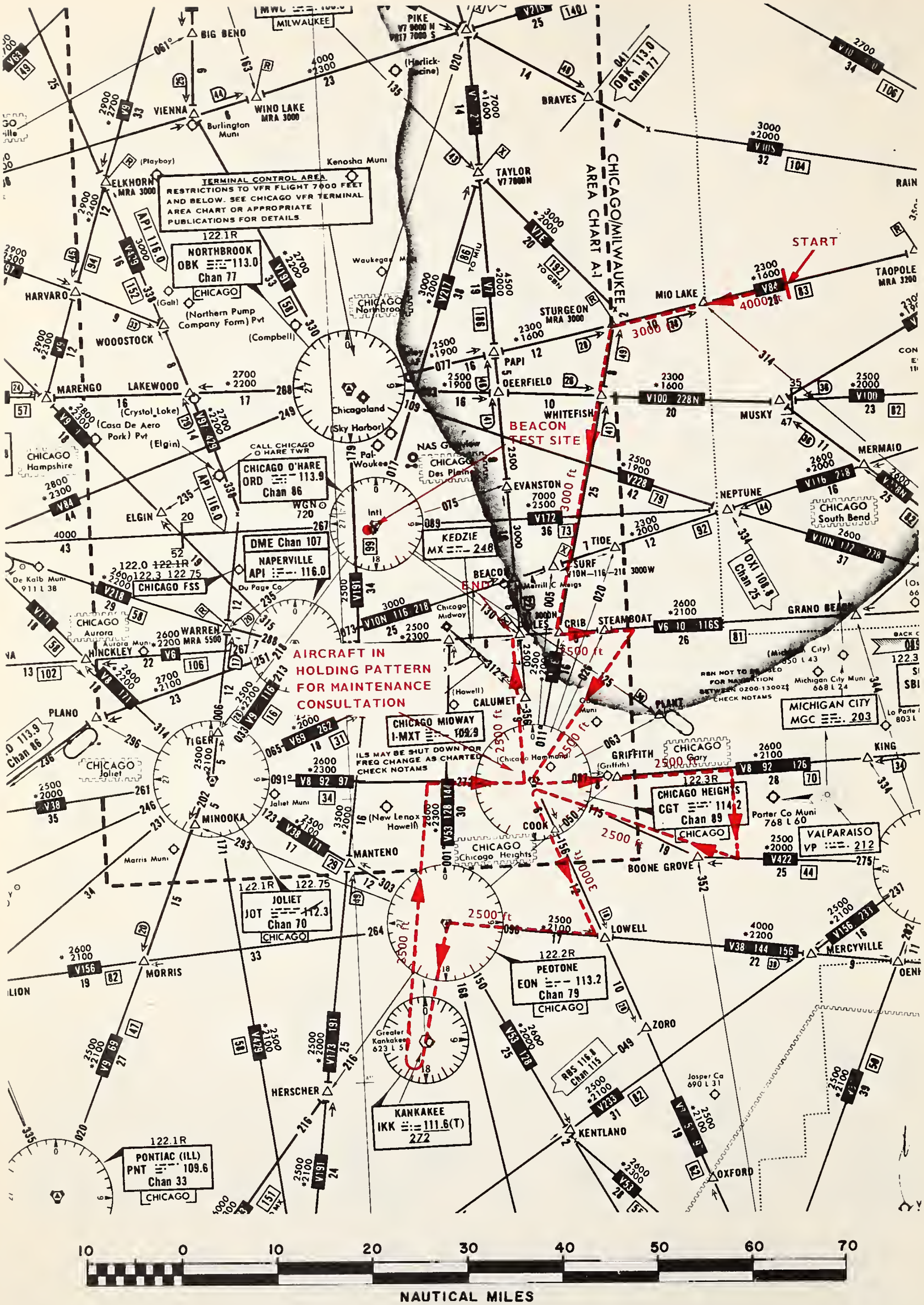


FIGURE 7. FLIGHT PATH OF FIDO LOW-ALTITUDE FLIGHT TEST CONDUCTED 22 SEPTEMBER IN THE MORNING

FIGURE 8. NAFEC AIRCRAFT CONVAIR 880M USED FOR FLIGHT TESTS

Two areas where reflected beacon replies occurred were investigated using the NAFEC aircraft and three areas where vertical lobing occurred were also flight tested. Prior to the completion of the flight testing on 2 October, the aircraft was flown over the beacon test site at 41,000 feet to measure the overhead coverage of the site at this altitude. An orbital flight test also conducted on 3 October (see Figure 9). The radius of this flight test was 150 nmi with the NAFEC aircraft flying at an altitude of 27,000 feet (FL 270).

RESULTS OF THE FLIGHT TESTS.

Even though the air traffic controllers did an excellent task of observing the beacon test site PPI display, they could not study all portions of the PPI display with equal measure. This was particularly true when more than one aircraft was displayed at a time; e.g., targets-of-opportunity data. When the filmed data was reviewed at NAFEC, during the week of 25 September, it was rerun many times. Each time the film was run, a different portion of the filmed PPI display was studied. This resulted in the detection of more problem areas than was originally suspected.

RESULTS OF THE TARGETS-OF-OPPORTUNITY TESTS.

SITE COVERAGE. On 14 September 1972, the air traffic controllers at the beacon test site recorded target information while observing targets-of-opportunity. The aircraft type, position, and altitude of displayed replies were coordinated with the Chicago Air Route Traffic Control Center located at Aurora, Illinois. Observations were made simultaneously at the Chicago Center and the beacon test site. The Chicago Center observed the McCook ARSR-2 radar beacon display, while the beacon test site observed their radar beacon display. The results of this radar beacon coverage coordination was as follows:

RANGE SELECTED - 100 NMI

Hours - 1000 to 1130

Aircraft Type	Position	Altitude
B707	5 Mi West of the TADPOLE Intersection	11,000
BE99	TADPOLE Intersection	8,000
BE80	15 Mi North East of the MIU VOR	9,000
AC21	10 Mi North East of the SBN VOR	FL-230
Cessna 310	Grand Beach Intersection	7,000
G159	5 Mi North East of TADPOLE Intersection.	14,000

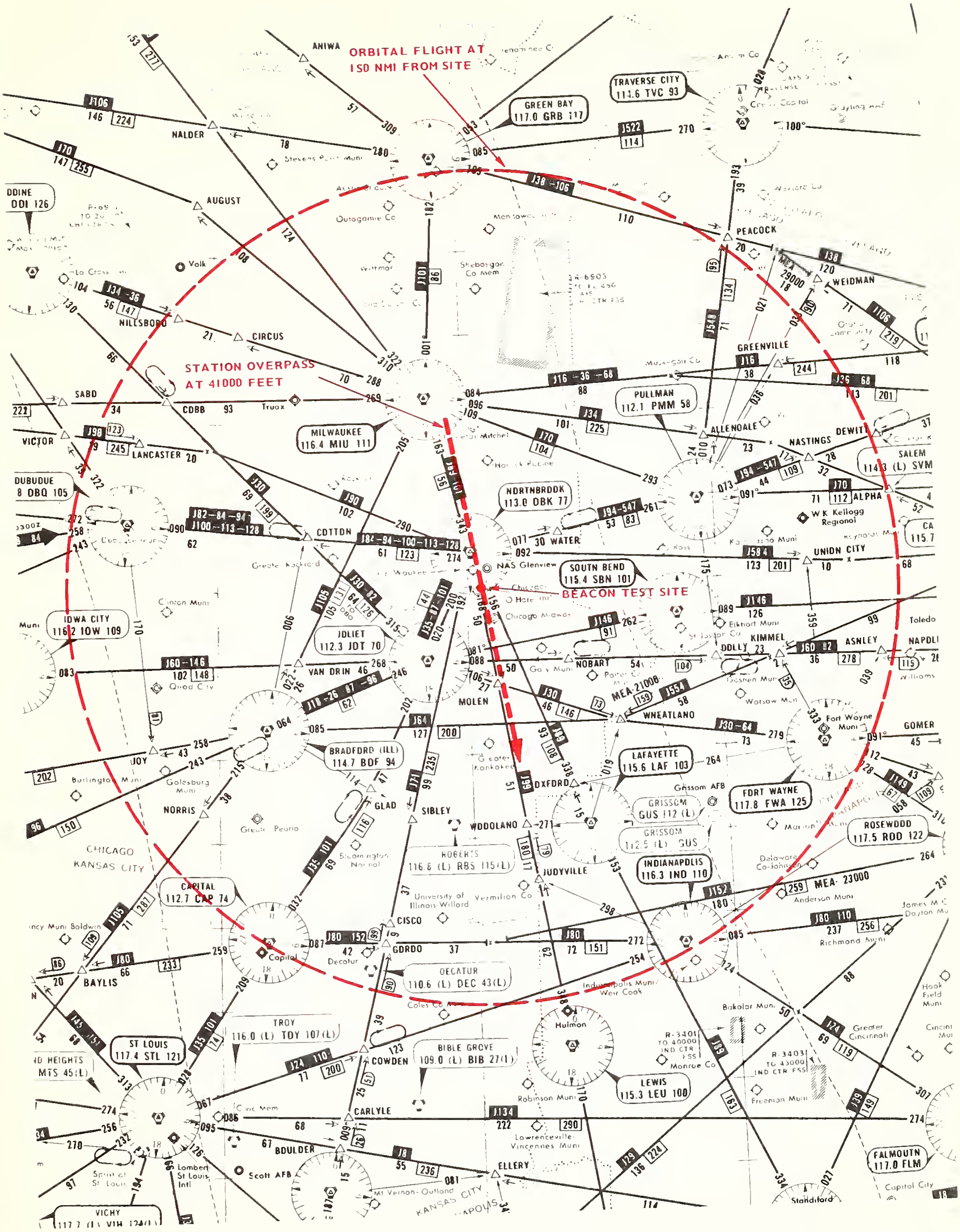


FIGURE 9. FLIGHT PATH OF NAFEC AIRCRAFT COVERAGE FLIGHT TESTS

Aircraft Type	Position	Altitude
BE55	12 Mi East of the Sunfish Intersection	8,000
	(NOTE: Ident. Feature Loud and Clear)	
PA28	10 Mi North East of the Taylor Intersection	9,000
BE90	Grand Beach Intersection	5,000
Cessna 411	10 Mi North East of the RBS VOR	11,000
Twin Otter	10 Mi East of the RBS VOR	8,000
Cessna 182	5 Mi North West of the CGT VOR	3,000
Unknown	5 Mi North East of Musky Intersection	7,000
DC9	2 Mi North East of ORD	2,500
Cessna 182	5 Mi West of the VPZ Airport	2,500
PA28	10 Mi East of the OXI VOR	6,000
Cessna 172	12 Mi South East of the OXI VOR	4,000
	Hours - 1245 to 1415	
B727	6 Mi North West of the JOT VOR	7,000
CV88	12 Mi North West of the RFD VOR	17,000
BE55	4 Mi North of the Lowell Intersection	5,000
BE80	10 Mi North East of the BDF VOR	7,000
	(NOTE: Ident. Feature Loud and Clear)	
Unknown	7 Mi South East of the Kentland Intersection	9,000
Twin Otter	15 Mi South West of the JOT VOR	6,000
BE90	15 Mi North East of the BDF VOR	7,000
PA28	10 Mi North of the BDF VOR	6,000
C119	3 Mi South of the Lakewood Intersection	4,000

Aircraft Type	Position	Altitude
UHI Helicopter	45 Mi West of ORD	3,000
	(Ident. Loud and Clear)	
Fairchild	10 Mi South East of the PLL VOR	9,000
C119	Malta Intersection	4,000
BE90	15 Mi North East of the JVL VOR	3,500
G159	10 Mi North East of the OXI VOR	13,000
Cessna 172	10 Mi West of the OXI VOR	4,000
NA265	8 Mi West of the GSH VOR	11,000
Unknown	15 Mi West of the SBN VOR	6,500
Unknown	7 Mi North East of Benton Harbor	7,500
BE55	2 Mi East of the Lowell Intersection	4,000
BE99	5 Mi East of the Zoro Intersection	5,000
AC68	3 Mi South of the Manteno Intersection	Climbing to 17,000
P2	Musky Intersection	5,000
BE55	5 Mi West of the EON VOR	4,000

Radar beacon coverage recordings were also made by the Air Traffic Controllers, at the beacon test site, on 15 September 1972. The individual radar beacon replies were grouped by transponder code and not by exact altitude. Observations were made of the azimuth, direction of flight, and the maximum range that the reply could be tracked. The results of these coverage tests were as follows:

RANGE SELECTED - 200 NMI

HOURS: 1000 to 1145

Code 1100 (Surface to flight level 230)

Azimuth (Degrees)	Maximum Range (nmi)	Direction
360	150	North
170	150	South
280	160	West
330	125	North West
040	110	North East
085	145	East
220	155	South West
190	95	South
110	120	East
095	130	South East

Code 1500 (Surface to flight level 230)

085	70	East
100	85	East
090	110	East
110	100	East
170	90	South
190	80	South
220	70	South West
260	65	West
360	85	North

Code 1700 (Surface to flight level 240)

350	60	North
080	70	East
070	80	East
100	90	East
110	100	East
170	85	South
240	100	South West
270	90	West
280	110	West

Codes 2100 and 2300 (Above flight level 240)

Azimuth (Degrees)	Maximum Range (nmi)	Direction
160	160	South
130	150	South East
300	160	North West
170	170	South
080	160	East
275	165	West
220	160	South West
290	165	North West
130	160	South East

Code 1200 (Surface to 9,500 Feet)

Azimuth (Degrees)	Maximum Range (nmi)	Direction
210	80	South West
190	50	South
160	90	South
320	110	North West
070	90	North East
130	120	South East

Code 1400 (Between 10,500 and 17,500 Feet)

Azimuth (Degrees)	Maximum Range (nmi)	Direction
100	145	East
260	110	West
280	100	West
350	150	North

REFLECTED BEACON REPLIES.

During the analysis of the targets-of-opportunity data at NAFEC, it was noted that aircraft replies suddenly appeared on the display and then just as suddenly disappeared. Some of these replies were approximately 60 to 80 nmi south of the beacon test site. From past experience it was assumed that these were reflected beacon replies. The criteria for determining whether a certain beacon reply is, in reality, a reflected beacon reply are as follows:

- The range of the reflected reply is always greater than the range of the normal beacon reply. Sometimes the added range is so insignificant that the difference is undetectable on the PPI display. (The flight path of the aircraft, during the rotation time of the antenna, must not be ignored in calculating this range), and

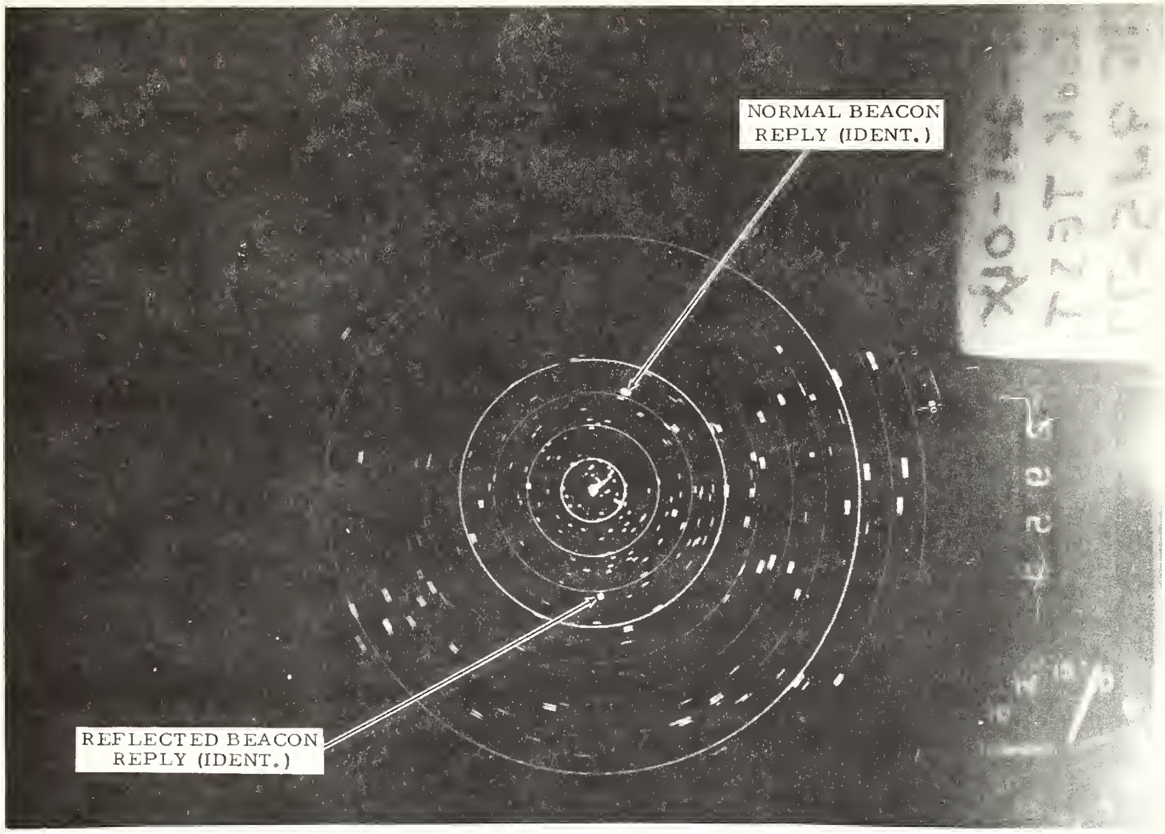
- The reply code of the normal beacon reply and the reply code of the reflected beacon reply must be identical; e.g., (a) both should display a single-slash or both should display a double-slash, (b) if the normal reply shows the "identification" feature, the reflected reply should also show the "identification" feature.

When this criteria was applied to the intermittent aircraft replies that occurred at the ranges of 60 to 80 nmi south of the beacon test site, the existence of reflected beacon replies in this area was confirmed. These reflected beacon replies extended from 203° to 172°, as the aircraft flew from 354° to 026°. The reflected beacon replies did not occur every rotation of the antenna, as the normal aircraft beacon reply covered the above azimuth changes, but a large number of reflected replies did occur during such flights.

Figure 10 shows two examples of reflected replies that were recorded on 15 September in this area. These photographs were selected because both the normal and the reflected beacon replies show the "identification" feature which confirmed the reflected beacon reply. The normal beacon reply was normally double-slashed; then showed the "identification" feature for two antenna rotations; and finally returned to a double-slashed return. The reflected reply followed the same sequence.

When the film data collected on 15 September was analyzed at NAFEC, a persistent "flashing" of replies was noted on the display 90 to 150 nmi north of the beacon test site. These intermittent reflected beacon replies were recorded between the azimuths of 10° to 15°. The reflected beacon replies in this area were traced to aircraft flying, at approximately the same range, in the vicinity of the 85° radial. The identification was made by comparing double-slashed codes and replies utilizing the "identification" feature. Figure 11 shows two examples of reflected replies that appeared in this area.

The reflected beacon replies that occurred between the ranges of 90 and 150 nmi and azimuths of 10° to 15° did not persist for more than four or five antenna rotations. Most of the reflected replies in this area lasted for only one or two antenna rotations. These reflected beacon replies were far less persistent than the reflected replies that occurred south of the beacon test site.



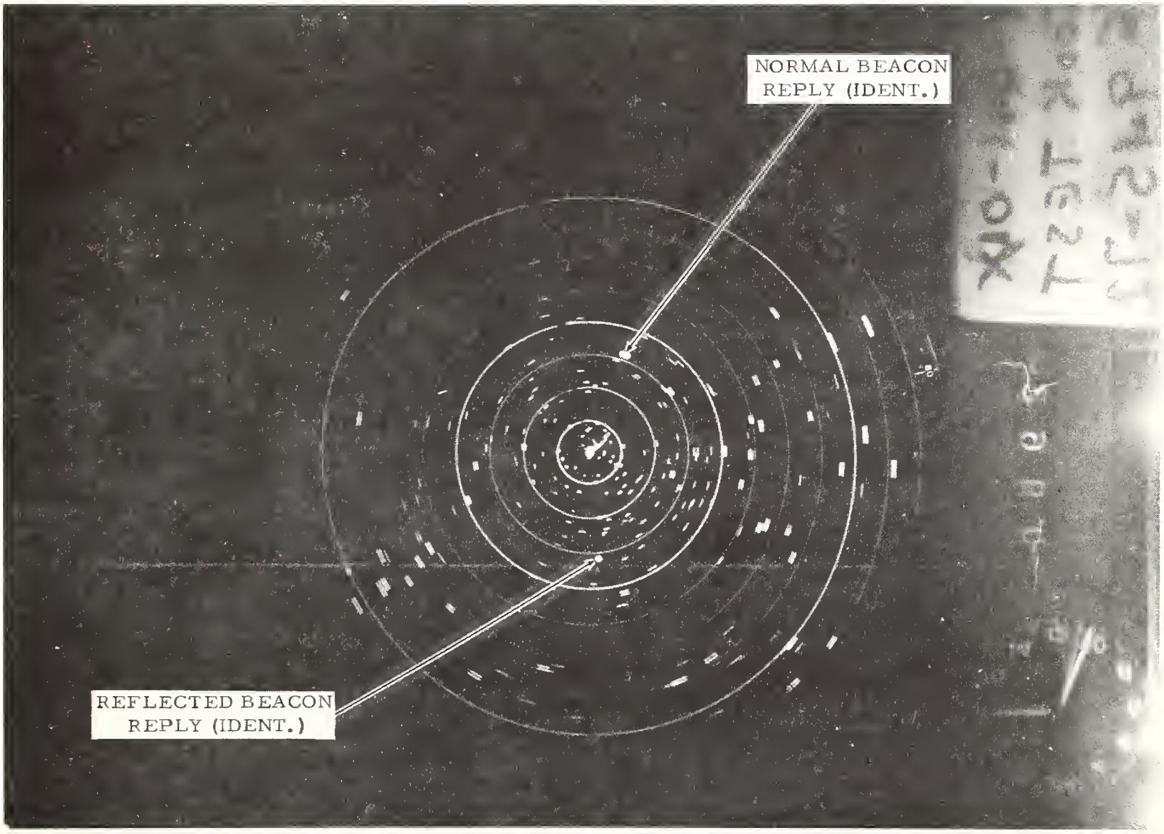


FIGURE 10. TWO EXAMPLES OF REFLECTED BEACON REPLIES RECORDED SOUTH OF THE BEACON TEST SITE DURING TARGETS-OF-OPPORTUNITY TESTS

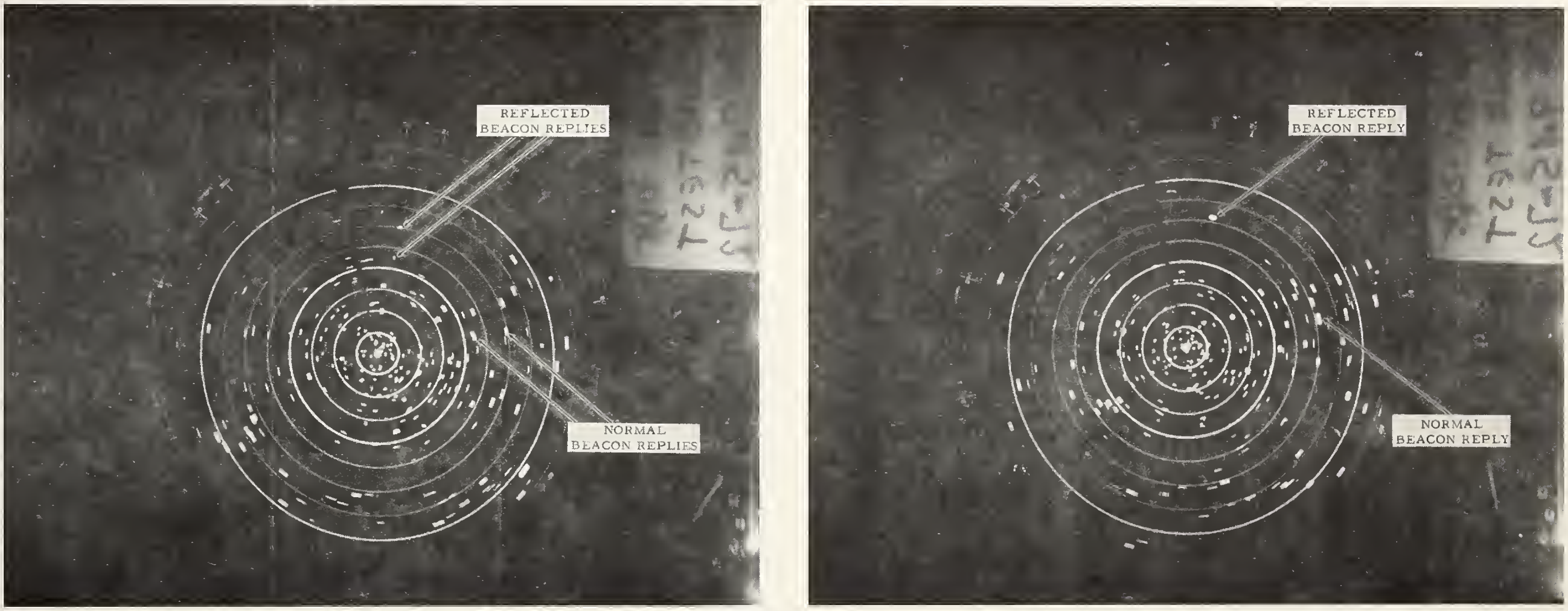


FIGURE 11. TWO EXAMPLES OF REFLECTED BEACON REPLIES RECORDED NORTH OF THE BEACON TEST SITE DURING TARGETS-OF-OPPORTUNITY TESTS

VERTICAL LOBING. During the analysis of the targets-of-opportunity data at NAFEC, the beacon replies were seen to diminish in width as the aircraft flew through certain coverage areas. Sometimes this decrease in the width of the beacon reply was so severe that the beacon reply was not seen for a number of antenna rotations. If the aircraft was changing course, the loss of beacon replies could have been attributed to the shielding of the aircraft antenna due to the turn maneuver. But in certain areas, the beacon reply was lost consistently when aircraft flew through this area even though the aircraft was not turning.

From past experience obtained from analyzing field site data, it was assumed that the narrowing and complete loss of beacon replies could, in this case, be attributed to propagation vertical lobing. Vertical lobing is a phenomenon that is produced by the reception of a radar beacon interrogation or reply over multiple propagation paths. If two propagation paths are available from the ground antenna to the aircraft antenna a cancellation of signal intensity will occur when the phasing of the two signals differ by approximately 180°. The intense signals that are reflected from large flat areas of terrain, due to the terrain being illuminated by the broad vertical pattern of the directional antenna, can cause very serious vertical lobing problems.

During the analysis of the targets-of-opportunity data at NAFEC, it was noted that aircraft replies were lost north of the beacon test site as aircraft flew along Jet Airway 38-106. The loss of replies occurred at 10°, 13° and 20° to a large number of aircraft that flew through the area. The range where the beacon replies were lost on Jet Airway 38-106 was approximately 145 nmi from the beacon test site. Figure 12 shows an example of the vertical lobing that occurred in this area. A series of photographs are shown so that the loss of the beacon reply could be associated with the position of the aircraft prior to and after the time the beacon reply was lost. The aircraft reply that exhibited vertical lobing was circled on the figure for easier identification.

The reason that all of the replies from aircraft that flew through the vertical lobing area were not lost is that the reduction of signal intensity, due to vertical lobing, is dependent upon the vertical angle of the aircraft relative to the beacon test site. The altitude of the aircraft that were seen on the PPI display during the analysis of the targets-of-opportunity data was not known. Therefore, the vertical angle of the aircraft relative to the beacon test site was also unknown. Two aircraft that appear at almost identical ranges and azimuths could still be separated by altitude. This would mean that the two aircraft were at different vertical angles relative to the beacon test site.

Another factor that should not be overlooked in analyzing flight test data, is that all aircraft transponders do not have equal receiver sensitivity or output power. The receiver sensitivity and output power are significant factors in the determination of why vertical lobing can reduce the beacon reply of one aircraft and not another even though the two aircraft are flying at similar ranges and azimuths.

FIGURE 12. LOSS OF BEACON REPLIES DUE TO VERTICAL LOBING ON THE 13° RADIAL OF THE BEACON TEST SITE

During the analysis of the targets-of-opportunity data, vertical lobing was also noted in the vicinity of the 71° to 89° radial, at ranges approximating 100 to 138 nmi. Aircraft flying on Jet Airways 94-547 and 584 covered these radials during their outbound and inbound flights. The three azimuths where the vertical lobing was most intense were 71°, 84°, and 89°. Vertical lobing was noted at two ranges on the 84° and 89° radials. Only one area of vertical lobing was noted on the 71° radial, this occurred at 130 nmi. Figure 13 shows an example of vertical lobing that took place on the 84° radial at 100 nmi.

Some loss of radar beacon replies was observed on the targets-of-opportunity data when aircraft flew in the vicinity of the 164° radial at ranges between 140 to 157 nmi. and on the 172° radial at ranges approximating 142 nmi. The loss of beacon replies did not occur too often in this area and it was questionable whether the loss of replies in this area was really very serious. Figure 14 shows an example of the loss of beacon replies that occurred in the vicinity of the 172° radial at a range of 142 nmi.

RESULTS OF FIDO AIRCRAFT FLIGHT TESTS.

HIGH-ALTITUDE FLIGHT TESTS. The results of the high-altitude flight tests, using the FIDO Aero Commander, Type AC21, reconfirmed the occurrence of vertical lobing in the beacon test site coverage, but no positive areas of reflected replies were recorded. The loss of the FIDO aircraft beacon return was discounted during turn maneuvers, but there were five instances when the beacon reply was lost while the aircraft was not turning.

Loss of the FIDO aircraft beacon reply occurred at azimuths of 310°, 331°, 10°, 13° and 19°. All of these losses of replies occurred at ranges between 110 and 143 nmi.

The loss of the FIDO aircraft beacon reply at 10° and 13° reconfirmed losses of radar beacon replies that had been previously recorded at these same azimuths during the targets-of-opportunity tests.

At the very end of the high-altitude flight tests, using a FIDO aircraft, the aircraft was flown directly over the beacon test site at an altitude of 27,000 feet. During this maneuver, the flight test aircraft reply was lost at a slant range of 5 nmi on one side of the site and reappeared at a slant range of 4 nmi on the other side of the site.

LOW-ALTITUDE FLIGHT TESTS. During the low-altitude flight tests, using a FIDO aircraft, the aircraft remained within 62 nmi of the beacon test site. Because the range of the flight test aircraft did not extend beyond the effective range of the improved 3-pulse SLS system, there were no reflected beacon replies recorded. Some reflected replies could have occurred if there was a reflecting surface less than 1,000 feet from the beacon test site antenna, but there was no indication that any efficient reflecting surface was within this range. The major contribution of the low-altitude FIDO flight tests was to confirm the beacon test site coverage.

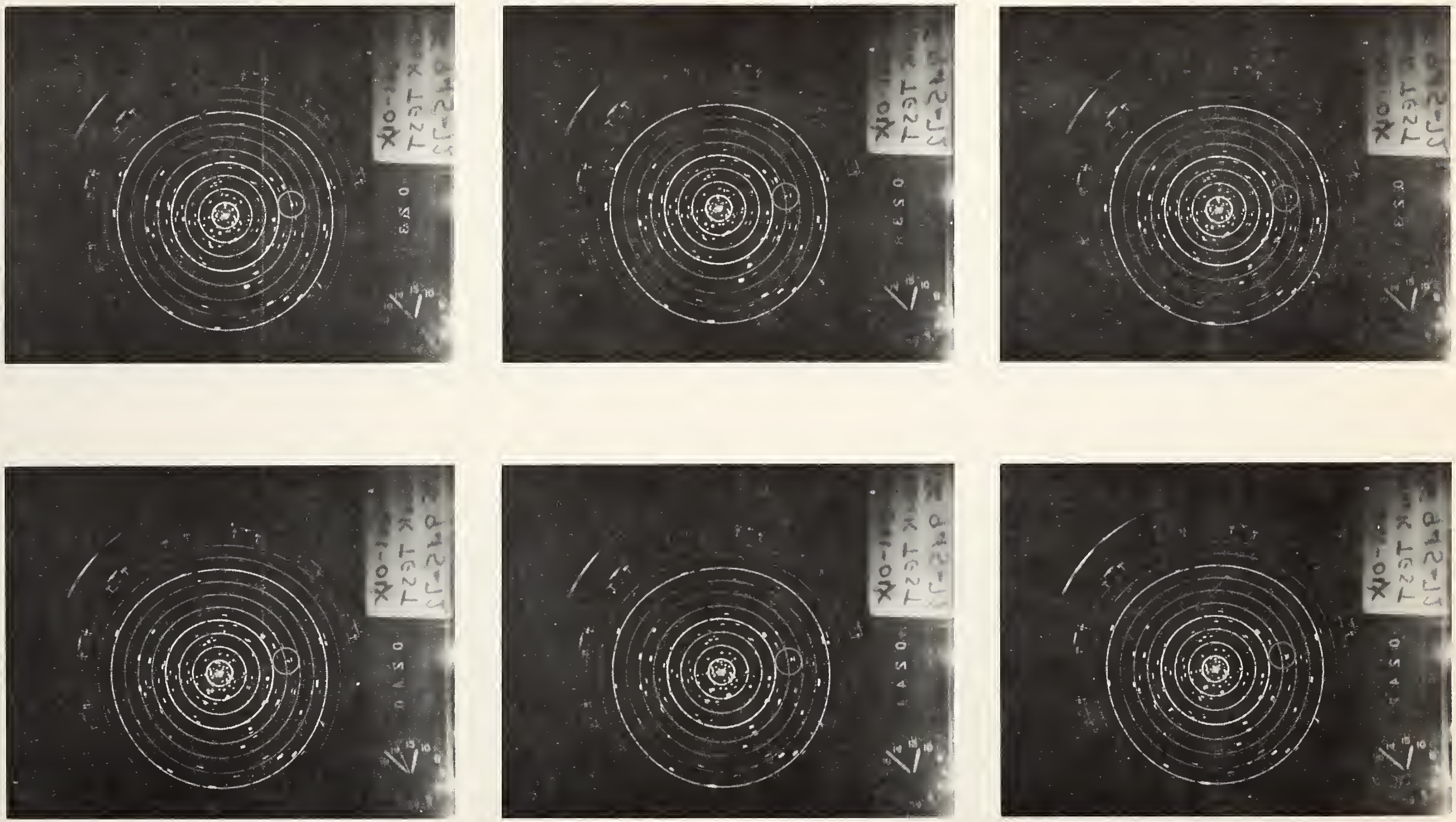


FIGURE 13. LOSS OF BEACON REPLIES DUE TO VERTICAL LOBING ON THE 84° RADIAL OF THE BEACON TEST SITE

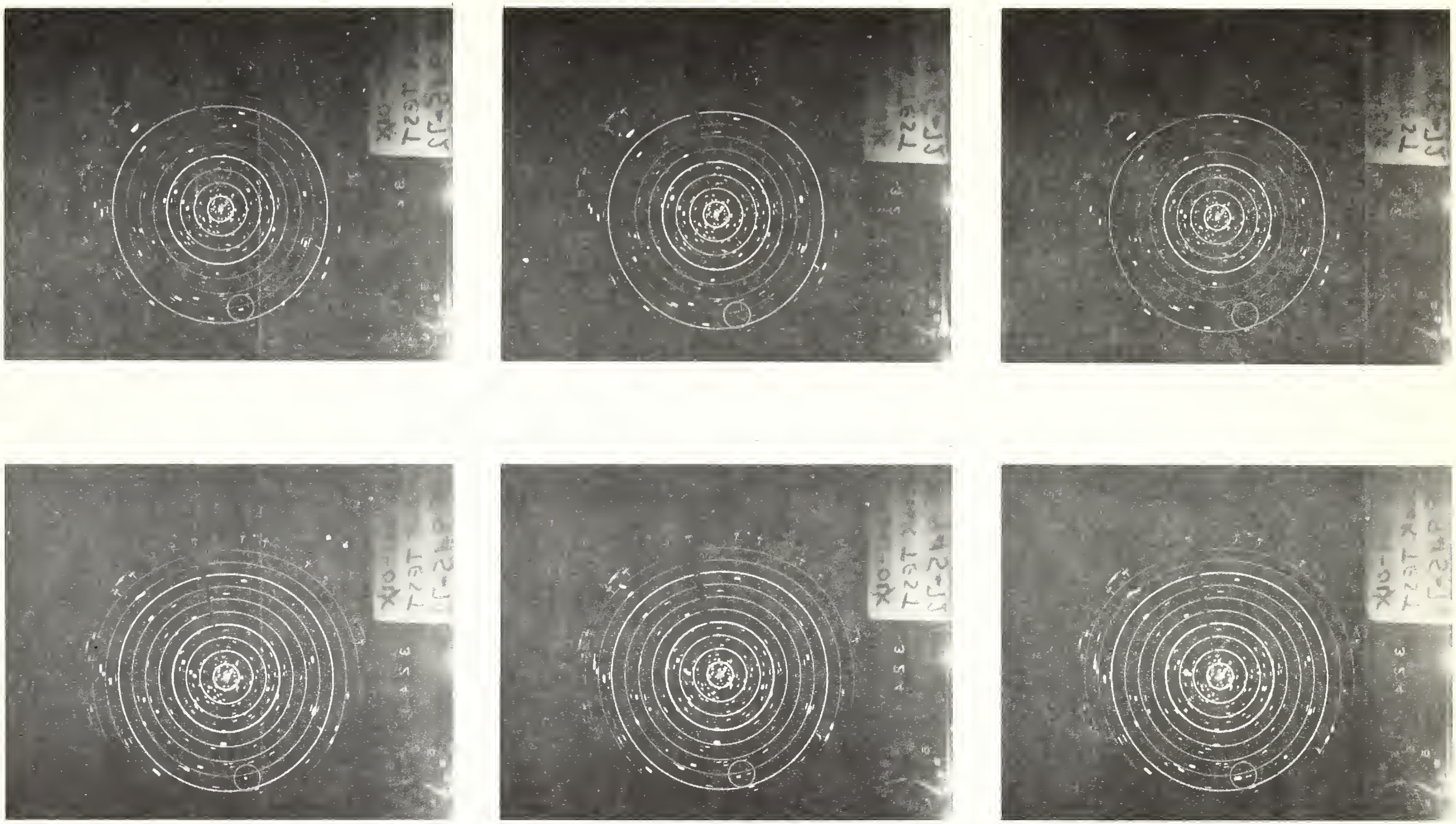


FIGURE 14. LOSS OF BEACON REPLIES DUE TO VERTICAL LOBING ON THE 172° RADIAL OF THE BEACON TEST SITE

Some "selected code" breakthrough that resembled reflected beacon replies, was seen during the low-altitude FIDO flight tests, but further investigation showed that these returns were due to code garbling that occurred between two unrelated aircraft replies. The flight test aircraft was also lost a number of times during turn maneuvers when the aircraft antenna was shielded by the aircraft wings or fuselage.

The low-altitude flight tests included a station overflight at 2,500 feet. During this flight maneuver, the aircraft beacon reply was lost at a slant range of 3/4 of a nmi on one side of the test site and reappeared at a slant range of 3/4 of a nmi on the other side of the test site.

RESULTS OF NAFEC AIRCRAFT FLIGHT TESTS.

Two different airborne equipment configurations were used during the NAFEC aircraft flight tests. The first equipment configuration used the aircraft's calibrated transponder, a Bendix Corp. Type TRU-1 Serial No. 55, which was interrogated by, and responded to, the beacon test site normal Mode 3/A interrogations. The antenna for this transponder was installed on the bottom of the aircraft beneath the cockpit.

The second equipment configuration that was used during the NAFEC aircraft flight tests, consisted of an airborne and ground-based synchronization system. This system was used ONLY during vertical lobing flight tests. A photograph of the airborne portion of this system equipment configuration is shown in Figure 15. A Radio Corporation of America (RCA) Transponder, Type 2.3NA1b/RT-1 Serial No. 1014, was used for the airborne portion of the system. The location of the antenna (Type 237Z-1), that was used with this transponder, is shown in Figure 8.

A block diagram of the entire equipment configuration, that was used during the vertical lobing flight tests is shown in Figure 16. This airborne and ground-based system was used as a synchronizing system to ensure that only the interrogations generated by the beacon test site were recorded in the aircraft, on the digital recorder.

The ground-base equipment for this system consisted of a transmitter, logic circuitry and an antenna. The transmitter was a Power Pulsed Signal Source, Model PG 5KA, fabricated by Applied Microwave Laboratory Inc., which was capable of producing 5 KW pulses at 1030 MHz. The transmitter was triggered by three pulses supplied by the logic circuitry. The first two pulses were separated by 25 μs to form a Mode D radar beacon interrogation. The third pulse (parity pulse) was transmitted 10 μs later, to prevent capture of the airborne equipment circuitry by false Mode D interrogation pulse spacings that might be occasionally produced by two nonsynchronous interrogators. The antenna that was used for the ground-based portion of the system was a Scientific Atlanta Standard Gain Horn, Model 11-0.9 (see Figure 17). The antenna was modified at NAFEC, by increasing the flare length. This provided increased directivity and gain.

The ground-based portion of the system used the "Beacon Sync" of the ATCBI-4 interrogator and the "North Mark" of the antenna system together with the logic circuitry, to generate 60 3-pulse "synchronizing" interrogations

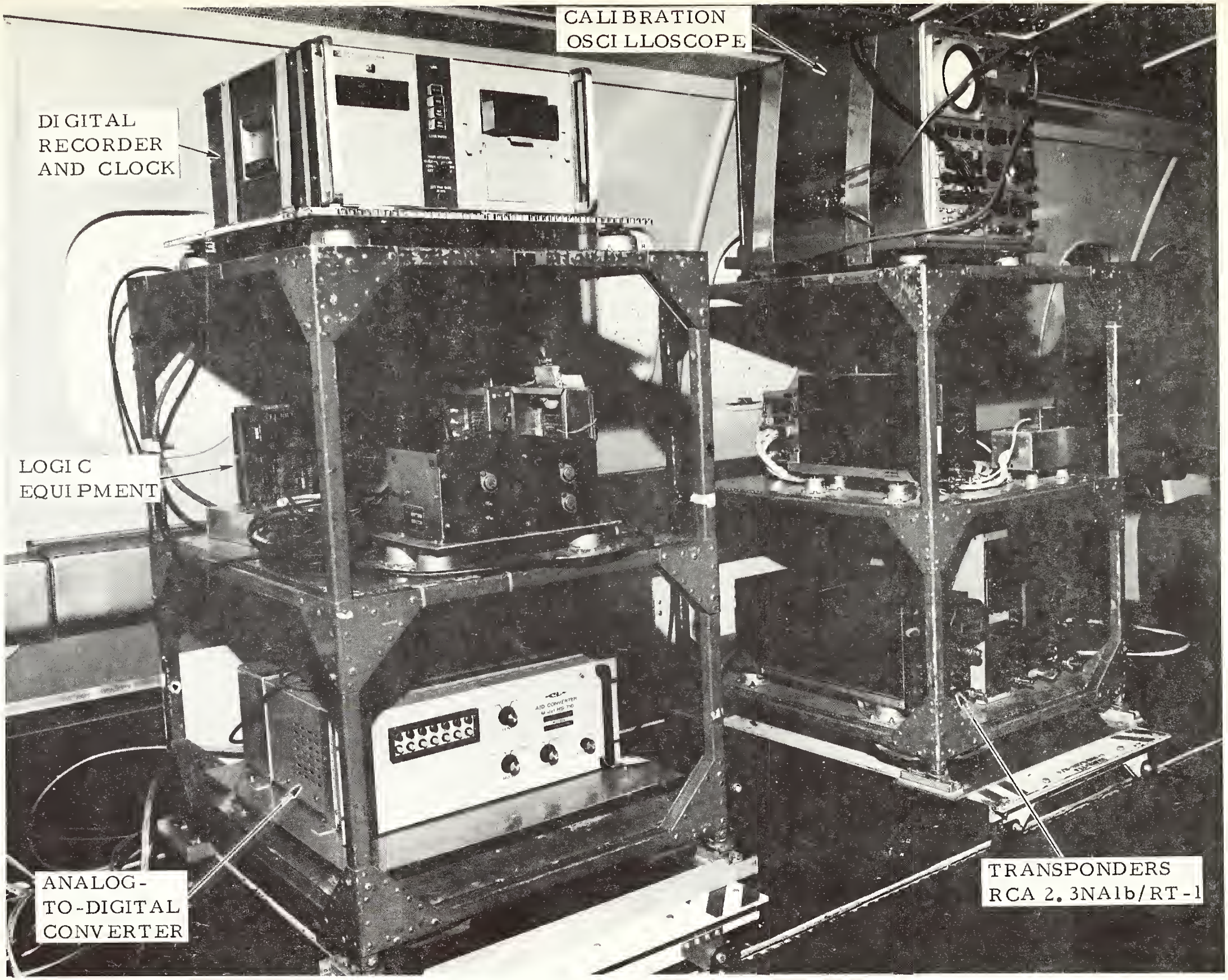


FIGURE 15. AIRBORNE SYSTEM EQUIPMENT CONFIGURATION INSTALLED IN NAFEC AIRCRAFT N 112

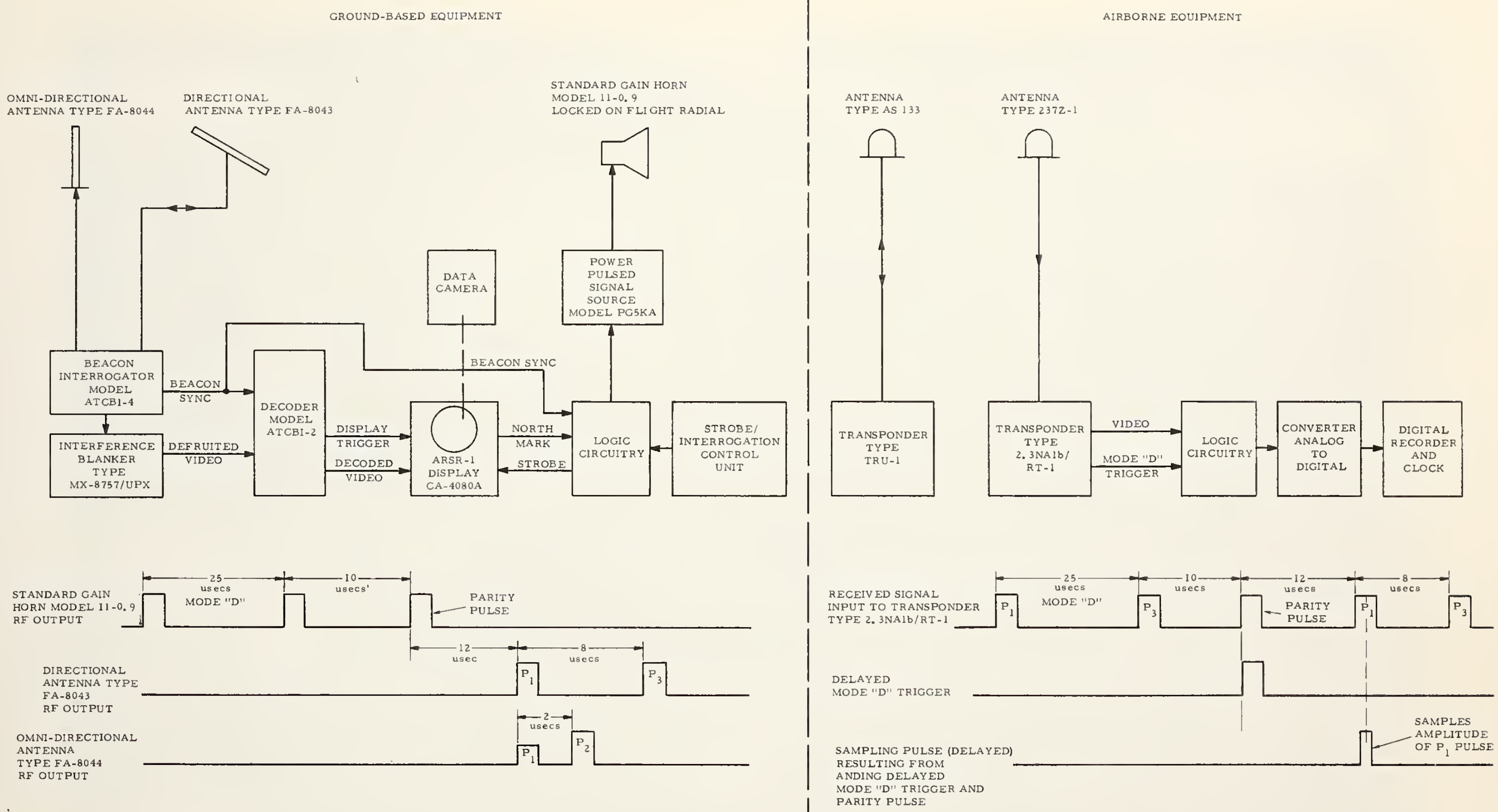


FIGURE 16. SYNCHRONIZATION SYSTEM BLOCK DIAGRAM

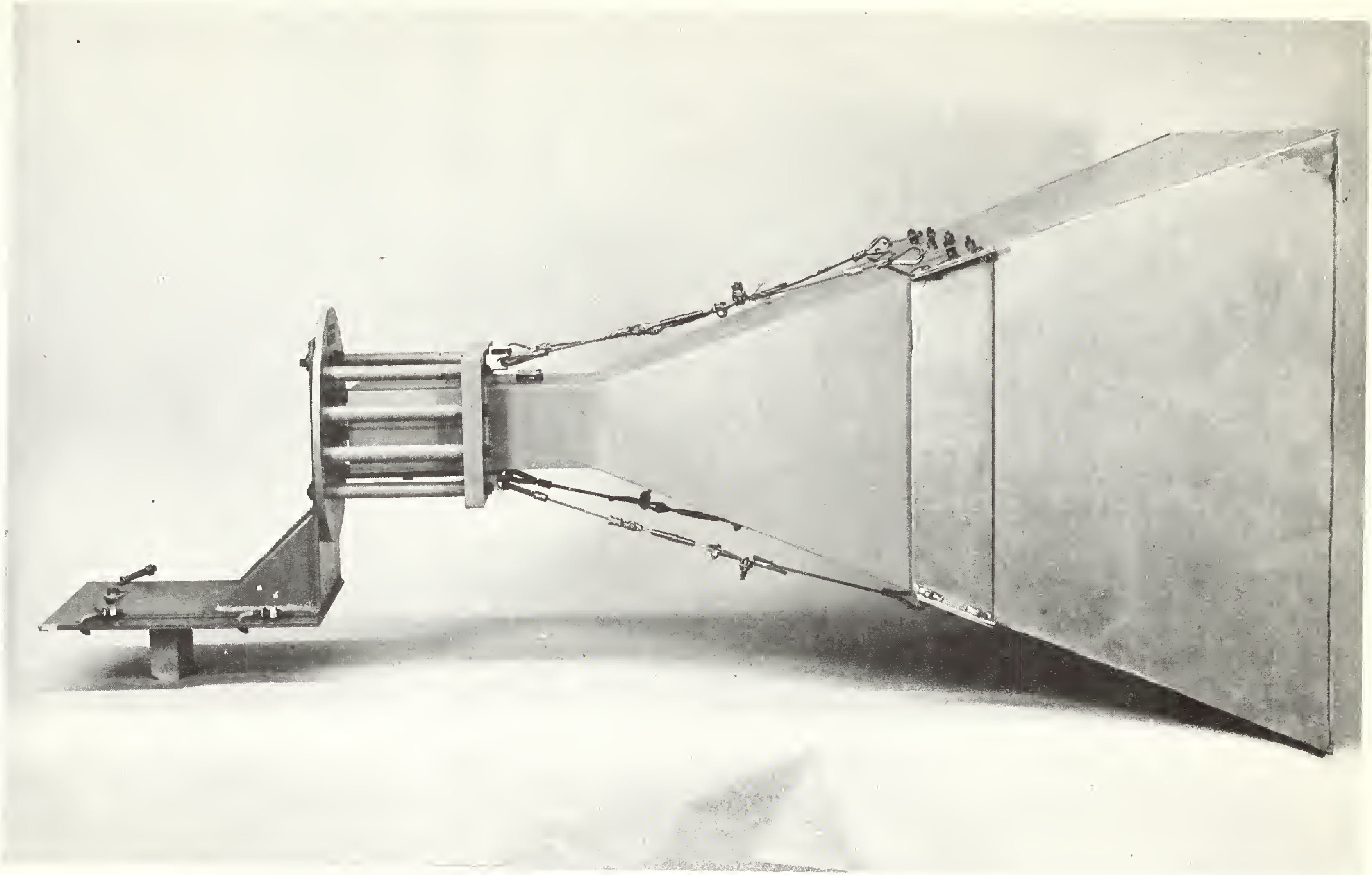


FIGURE 17. MODIFIED STANDARD GAIN HORN ANTENNA THAT WAS USED AT THE BEACON TEST SITE TO TRANSMIT THE "SYNCHRONIZING" INTERROGATION

for each antenna rotation. The logic circuitry provided the means for not only controlling the precise azimuth where the 60 "synchronizing" interrogations began, but also supplied a strobe for the PPI display. The timing of the 60 3-pulse "synchronizing" interrogations were made to coincide with the interrogation of the flight test aircraft by the main beam of the directional antenna. This was accomplished by shifting the position of the strobe on the PPI display. The strobe was placed on the counterclockwise edge of the flight test aircraft reply. This positioning of the strobe caused the next 60 3-pulse "synchronizing" interrogations to be transmitted to the flight test aircraft, approximately 12 μs, prior to the transmission of the normal Mode 3/A interrogation from the directional antenna.

The airborne portion of the synchronizing system, (Figure 16), consisted of an antenna, transponder, logic circuitry, analog-to-digital converter and a digital recorder. The reception of the Mode D interrogation by the transponder produced a trigger for the logic circuitry which was "ANDED" with the parity pulse. The pulse that was produced by the "AND" circuit was delayed to coincide with the P_1 pulse of the normal Mode 3/A beacon site interrogation, so that the amplitude of the P_1 interrogation pulse could be sampled. The analog-to-digital converter changed the amplitude of the P_1 interrogation pulse into a digital code which was recorded on the digital recorder along with the time of the recording.

In order to record the amplitude of 60 consecutive P_1 interrogation pulses in the main beam of the beacon test site directional antenna, the digitized amplitude of each P_1 interrogation pulse was stored in a 7 x 60 bit shift register. After a time interval equivalent to five interrogation periods had elapsed without receiving a Mode D interrogation, the digitized amplitude of the P_1 interrogation pulses that were stored in the shift register were transferred to the digital recorder and printed. Figure 18 shows a typical recording produced in this manner. The time of recording is shown on the left in hours, minutes, seconds and tenths of seconds while the data is recorded on the right. Each of the two digits of data can assume a value between zero and *. An increase or decrease of one in the numerical value of the number in the far righthand column indicated a change in the pulse amplitude of 16 millivolts. A recorded one was equivalent to 16 millivolts, while a recorded one* was equivalent to 496 millivolts. The series being 0, 1,2,3,4,5,6,7,8,9,+,-,V,A,Ω,*. Figure 18 shows data that was recorded during the vertical lobing flight testing. The recorded data show how the amplitude of the directional antenna main beam varied with azimuth.

A system calibration was performed, at NAFEC, prior to departure for Chicago, to allow converting the transponder input, in -dBm, to the appropriate digits that were recorded on the digital recorder. The calibration tests showed that a -64 dBm level at the input to the transponder was recorded as a three on the digital recorder, while an input level of -15 dBm was recorded as a 69. The synchronization system was effective to ranges beyond 150 nmi but the amplitude of the normal Mode 3/A interrogation P_1 pulse could not be recorded at levels below -65dBm. This limited the effective range of the entire system to approximately 120 nmi. This limitation was caused by a Honeywell 3C Schmitt Trigger Circuit which converted the Mode 3/A video pulse.

1540315	
1540315	
1540314	
1540314	
1540313	
1540313	
1540312	
1540312	1
1540311	4
1540311	4
1540311	7
1540310	8
1540310	-
1540309	A
1540309	Ω
1540308	A
1540308	*
1540307	1 2
1540307	1 2
1540306	1 4
1540306	1 4
1540305	1 2
1540305	1 4
1540304	1 5
1540304	1 7
1540304	1 6
1540303	1 4
1540303	1 3
1540302	1 4
1540302	1 5
1540301	1 4
1540301	1 4
1540300	1 2
1540300	1 2
1540299	V
1540299	Ω
1540298	A
1540298	A
1540297	-
1540297	8
1540297	6
1540296	4
1540296	2
1540295	1
1540295	
1540294	
1540294	
1540293	
1540293	
1540292	
1540292	
1540291	

FIGURE 18. DATA FROM THE BEACON TEST SITE THAT WAS RECORDED, IN THE NAFEC AIRCRAFT, USING THE SYNCHRONIZING SYSTEM

A more sensitive Schmitt Trigger is needed to extend the range of the system to at least 150 nmi. The system was still effective in verifying vertical lobing that took place in Chicago at ranges less than 120 nmi.

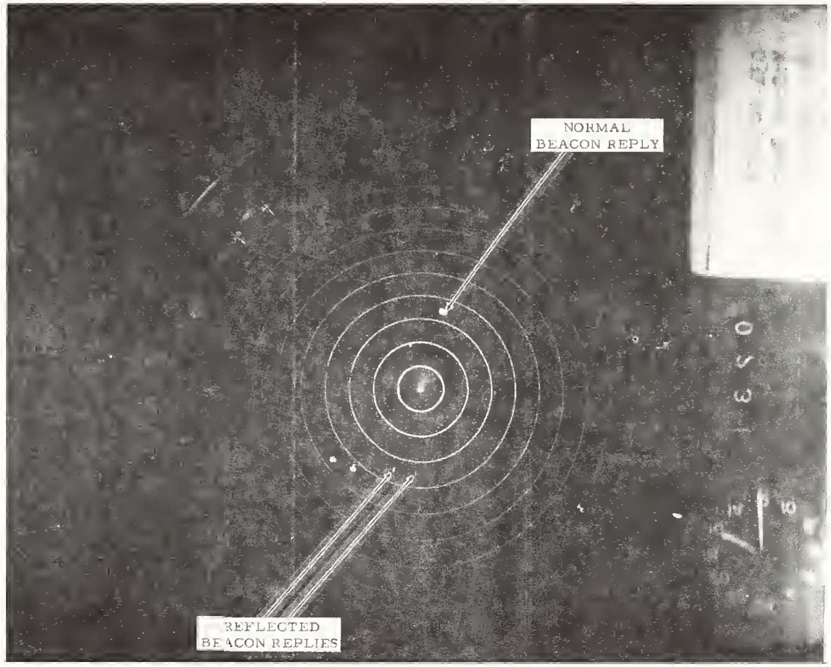
The flight tests that were conducted, using NAFEC aircraft N-112 on 2 October, were flown to reconfirm reflected beacon replies that were obtained during the targets-of-opportunity tests. The NAFEC aircraft flight tests were made at ranges approximating 64-80 nmi in an attempt to reproduce reflected replies south of the beacon test site. The flight tests were made at 25,000, 27,000, 29,000 and 31,000 feet. All of the flight tests produced some refelcted beacon replies at azimuths from 205° to 150° as the aircraft was flown between site azimuths of 345° to 24°. Figure 19 shows two examples of dual reflections that occurred during these flight tests.

The NAFEC aircraft was flown directly over the beacon test site at 41,000 feet on 2 October 1972. During this maneuver, the aircraft replies were lost at 344° at a slant range of 9.5 nmi and were received, after the station crossing, at 169° at a slant range of 9 nmi.

Flight tests were conducted on 3 October in the vicinity of the beacon test site 82° to 90° radials. The purpose of these flight tests was to produce reflected beacon replies north of the beacon test site which would reconfirm the reflected beacon replies recorded during the targets-of-opportunity tests. During the NAFEC aircraft flight tests at altitudes between 24,000 and 31,000 feet, reflected beacon replies were recorded between 6° and 15°. The reflected replies that occurred at an azimuth of 15° reconfirmed the reflected replies recorded during the targets-of-opportunity tests at the same radial. The reflected replies that occurred at an azimuth of 15° were produced as the aircraft was flown in the vicinity of the 83° radial. Figure 20 shows reflected beacon replies that occurred at 15° and 355° when the NAFEC aircraft was flown at 83° and 99°, respectively. The reflected replies that occurred at 355° were produced during the orbital flight test that was conducted at the end of the flight testing on 3 October.

Vertical lobing was also recorded during the NAFEC aircraft flight tests that took place on 3 October. The most severe case of vertical lobing occurred as the aircraft was flown on the 77° and 84° radials.

The orbital flight test that was flown at 27,000 feet on 3 October was conducted to investigate the beacon test site coverage and determine if obstructions on the site horizon would interfere with the beacon test site coverage. The only extended loss of the NAFEC aircraft beacon reply that did occur during the orbital flight was not due to obstructions but due to a change in the transponder code that was requested by the Indianapolis, Indiana, Center. The code change was not coordinated with the beacon test site. This caused a loss of the NAFEC aircraft beacon reply for 10 antenna rotations between the site azimuths of 180° and 175°. During the orbital flight test, reflected beacon replies were recorded on the 355°, 1°, 5° and 10° radials as the NAFEC aircraft was flown through site azimuths of 99°, 87°, 87° and 267°, respectively.



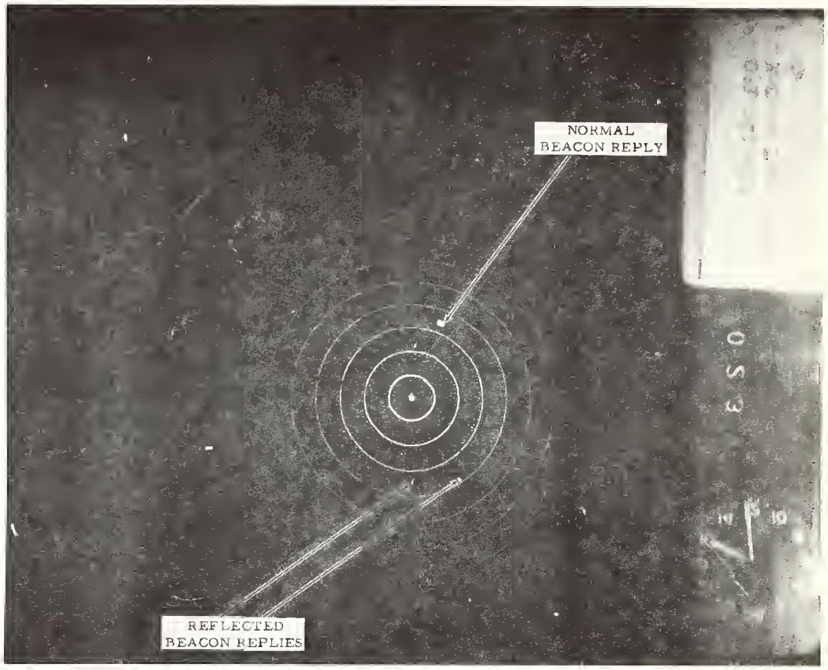


FIGURE 19. REFLECTED BEACON REPLIES RECORDED SOUTH OF THE BEACON TEST SITE DURING THE NAFEC AIRCRAFT FLIGHT TESTS

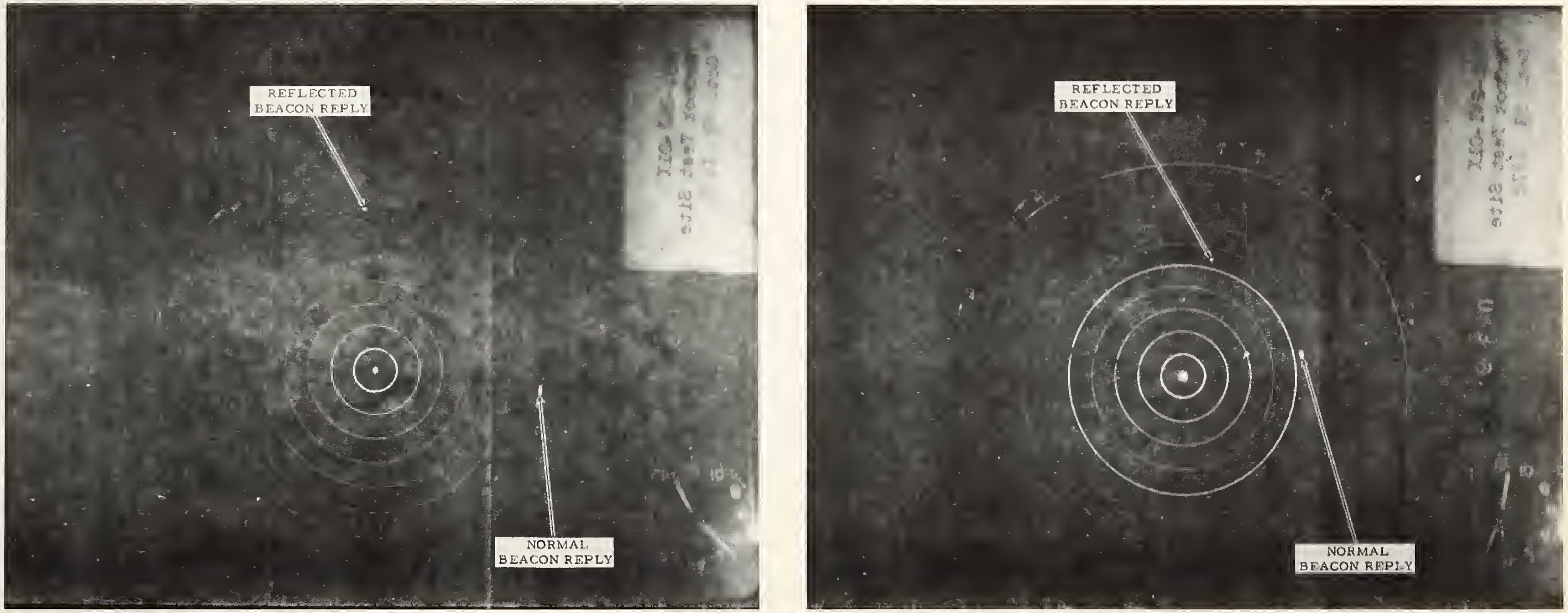


FIGURE 20. REFLECTED BEACON REPLIES RECORDED NORTH OF THE BEACON TEST SITE DURING THE NAFEC AIRCRAFT FLIGHT TESTS

Vertical lobing caused a loss of the beacon reply in the northern sector at 358° and 15° during the orbital flight test. A more detailed listing of the reflected beacon replies that occurred during the flight testing on 2 and 3 October can be found in the Appendix.

Flight tests, using the NAFEC aircraft, were conducted on 4 and 5 October, to investigate areas that had produced a loss or narrowing of beacon replies during the targets-of-opportunity tests. The first area that was investigated, in an attempt to record vertical lobing, was north of the beacon test site. The flight tests were made in the vicinity of the 10° to 18° radials at an altitude of 25,000 feet. The major portion of the beacon replies that were lost during these tests were between 98 and 153 nmi on the 10° and 16° radials. Some beacon replies were also lost between 98 and 133 nmi on the 13° radial of the beacon test site. Figure 21 shows a loss of beacon replies that occurred on the 13° radial at 125 nmi due to vertical lobing. A series of three photographs are shown to illustrate where the aircraft reply appeared prior to and after the loss of replies occurred.

During the morning of 4 October, the timing signal that was used for the digital recorder clock was supplied directly from the aircraft's 60-Hertz power source. This introduced an error due to the 60-Hertz power source frequency shift which occurred over a period of time. A Time-Mark Generator, Tektronix Type 2901, used to provide a very accurate timing signal for the digital recorder clock, was not functioning during the morning flight on 4 October. The time-mark generator problem was resolved at noon on 4 October, and the generator functioned normally for the remainder of the flight tests.

Flight tests were conducted, in the afternoon of 4 October, on the beacon test site radials between 60° and 75°. A large portion of the losses of beacon replies that occurred during the targets-of-opportunity tests were lost on the 71°, 84° and 89° radials. Since extensive flight testing was accomplished on the 84° radial during the flight tests that were performed on 3 October, flight testing on the 84° radial was not repeated. On 3 October, losses and narrowing of targets were detected on the 84° radial at 120 nmi (Figure 22). Some loss of beacon replies was also recorded on 3 October on the 84° radial at 110, 155 and 170 nmi. Losses and narrowing of beacon replies were recorded on 3 October at ranges of 115, 123 and 133 nmi on the 77° radial and at 135 nmi on the 89° radial (see Appendix).

The flight tests that were conducted, during the afternoon of 4 October, showed definite loss and narrowing of beacon replies on the 71° radial at ranges of 65, 106, 115, 126 and 134 nmi. Some narrowing of beacon replies was recorded on the 60° radial at 71 nmi.

During the flight testing that was conducted on 4 October, some reflected beacon replies were recorded. The reflected replies occurred between 201° and 177° when the aircraft was flown between 357° and 21° at ranges between 51 and 76 nmi (see Appendix).

FIGURE 21. LOSS OF BEACON REPLIES DUE TO VERTICAL LOBING ON 13° RADIAL OF THE BEACON TEST SITE DURING NAFEC AIRCRAFT FLIGHT TESTS

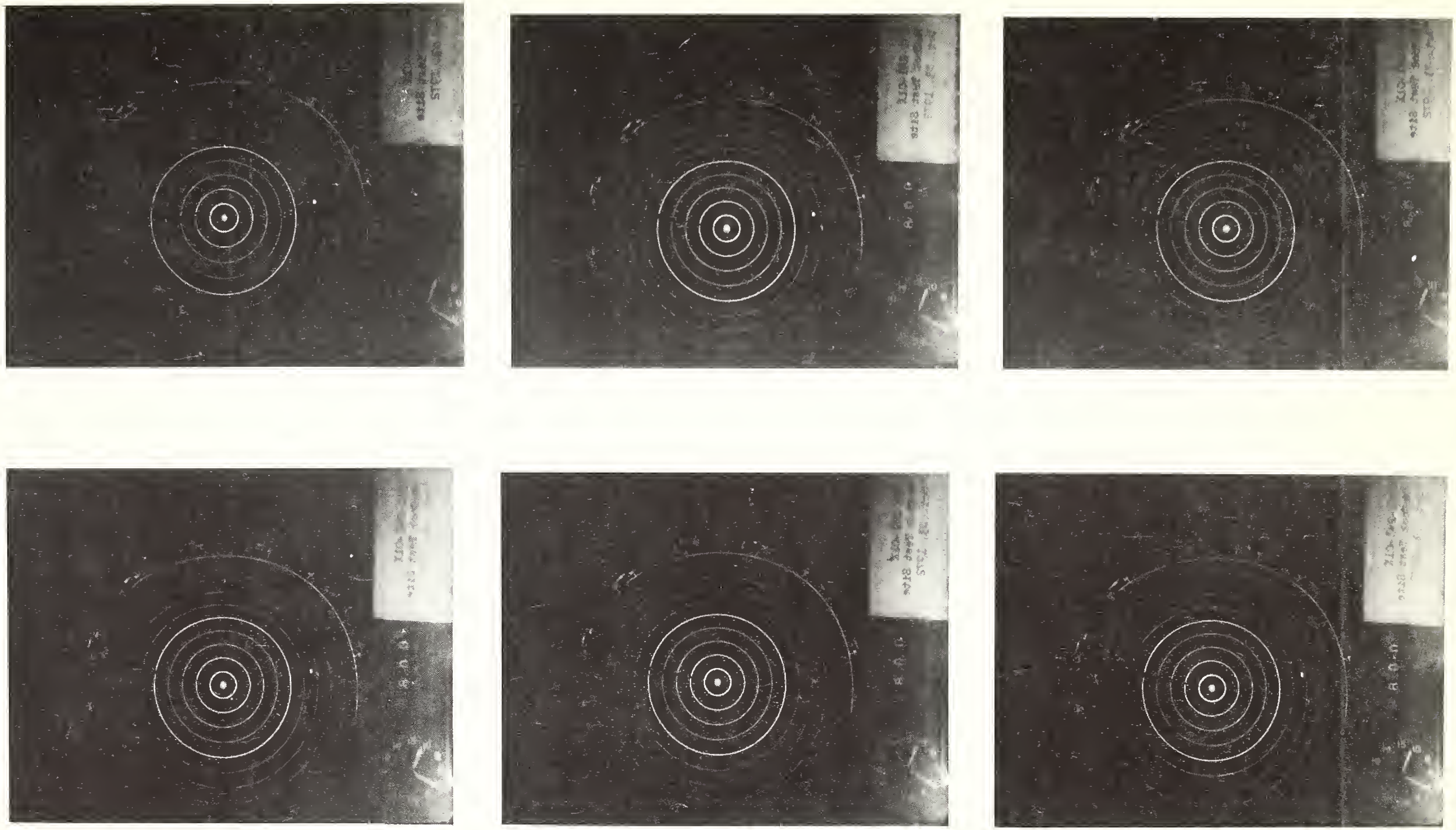


FIGURE 22. LOSS OF BEACON REPLIES DUE TO VERTICAL LOBING ON 84° RADIAL OF THE BEACON TEST SITE DURING NAFEC AIRCRAFT FLIGHT TESTS

The flight testing that was conducted on 5 October, using the NAFEC aircraft, commenced by investigating the 165° to 175° beacon test site radials at 27,000 to 29,000 feet. The flight tests were made in an attempt to produce losses of beacon replies in this area, but no complete loss of beacon replies was noted except during turn maneuvers. Some narrowing of the beacon reply was recorded on the 162° radial at 72 nmi and on the 170° radial at 79 nmi. Figure 23 shows the narrowing of the beacon reply that occurred on the 170° radial at 79 nmi.

At the completion of the flight testing in the vicinity of the 165° to 175° radials, the weather at the O'Hare Airport was below the minimum safe landing requirements so the aircraft could not land. Flight testing was continued on the 83° radial of the beacon test site awaiting a weather change. After the flight test was completed, the aircraft was flown to Green Bay, Wisconsin, via the Peacock Intersection. By this time the weather had cleared and the aircraft was flown back to the O'Hare Airport where it was landed. During the maneuvering after the aircraft left the 83° radial, the pilot did not try to maintain the aircraft in straight and level flight as he had done prior to this time. This resulted in more serious losses of beacon replies during the later portion of the flight testing on 5 October 1972.

CAUSES OF SITE PROBLEMS AND POSSIBLE SOLUTIONS.

The problems that were observed during the flight testing and analysis of data recorded at the beacon test site can be divided into two groups. There were beacon replies due to reflections and loss or narrowing of the beacon replies. Both of these problem areas can be related to the broad vertical pattern of the directional antenna, particularly the loss or narrowing of the beacon replies. If the energy radiated from the directional antenna could have been confined to vertical angles above the horizon, the beacon test site would have been virtually free of problems. Considerable FAA research and development effort is presently being expended in the development of radar beacon antennas that radiate a controlled vertical pattern. This is in the hope of eliminating or greatly reducing future beacon problems due to reflected replies and the loss of beacon replies due to vertical lobing.

REFLECTED BEACON REPLY PROBLEMS. The reflected beacon replies, that were recorded at the beacon test site, were limited mainly to two areas. These areas were both north and south of the beacon test site. The reflected replies that occurred in the south were confined to site azimuths between 150° and 205° (see Appendix). From the panoramic photographs of Figure 24 that were taken at the beacon test site at a height of 75 feet, it can be seen that the reflecting surface is either the fence along Irving Park Road or the buildings and boxcars in the freight yard across Irving Park Road.

The replies that were caused by the reflecting surface in the south were limited to ranges between 53 and 80 nmi. These reflected replies should have been eliminated by the improved 3-Pulse SLS system radiation but the data shows that the system capability was limited to approximately 53 nmi. Normally, the improved 3-Pulse SLS system is effective to ranges approximating 80 nmi.

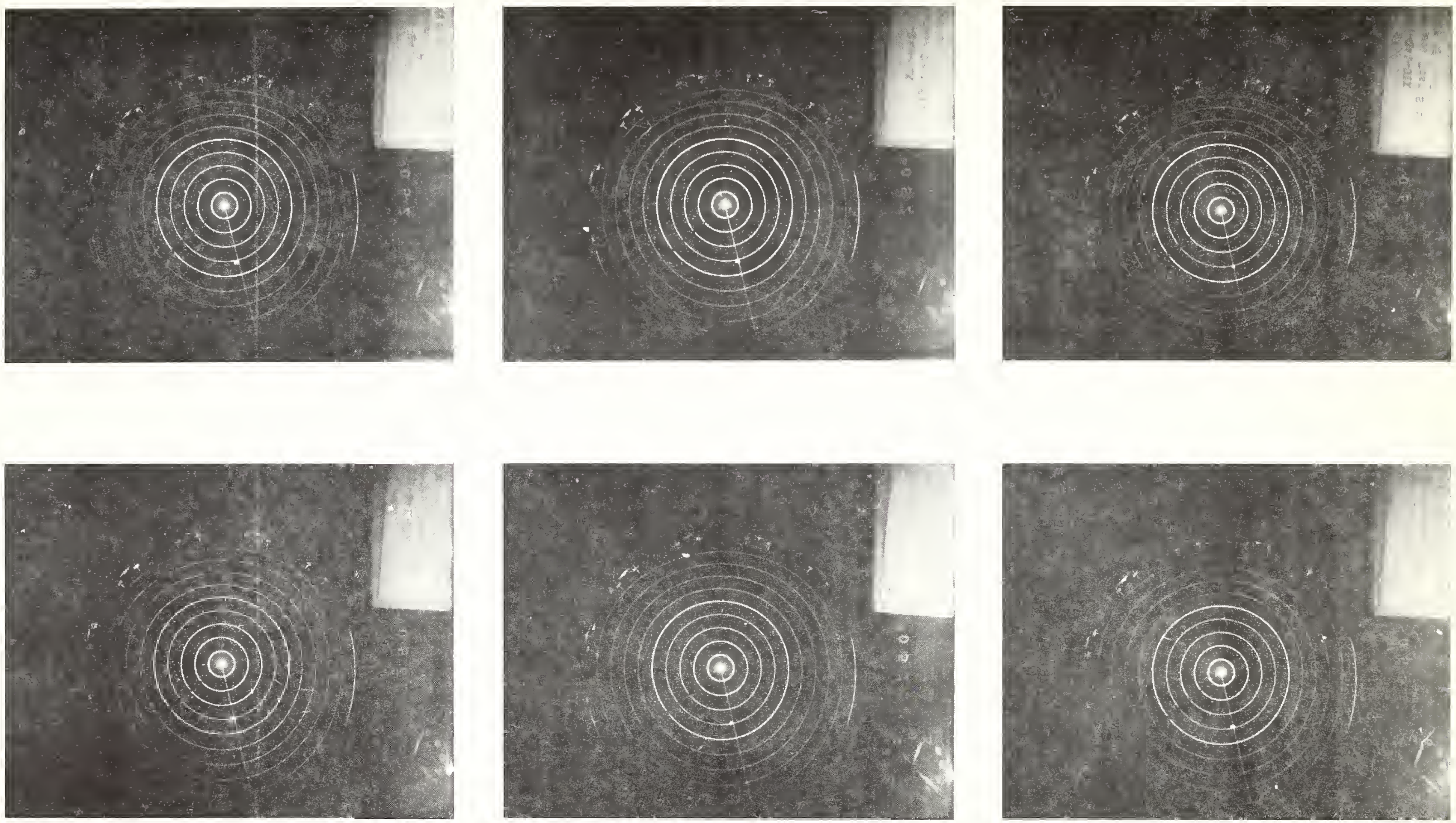


FIGURE 23. REDUCTION OF BEACON REPLIES DUE TO VERTICAL LOBING ON 170° RADIAL OF THE BEACON TEST SITE DURING NAFEC AIRCRAFT FLIGHT TESTS

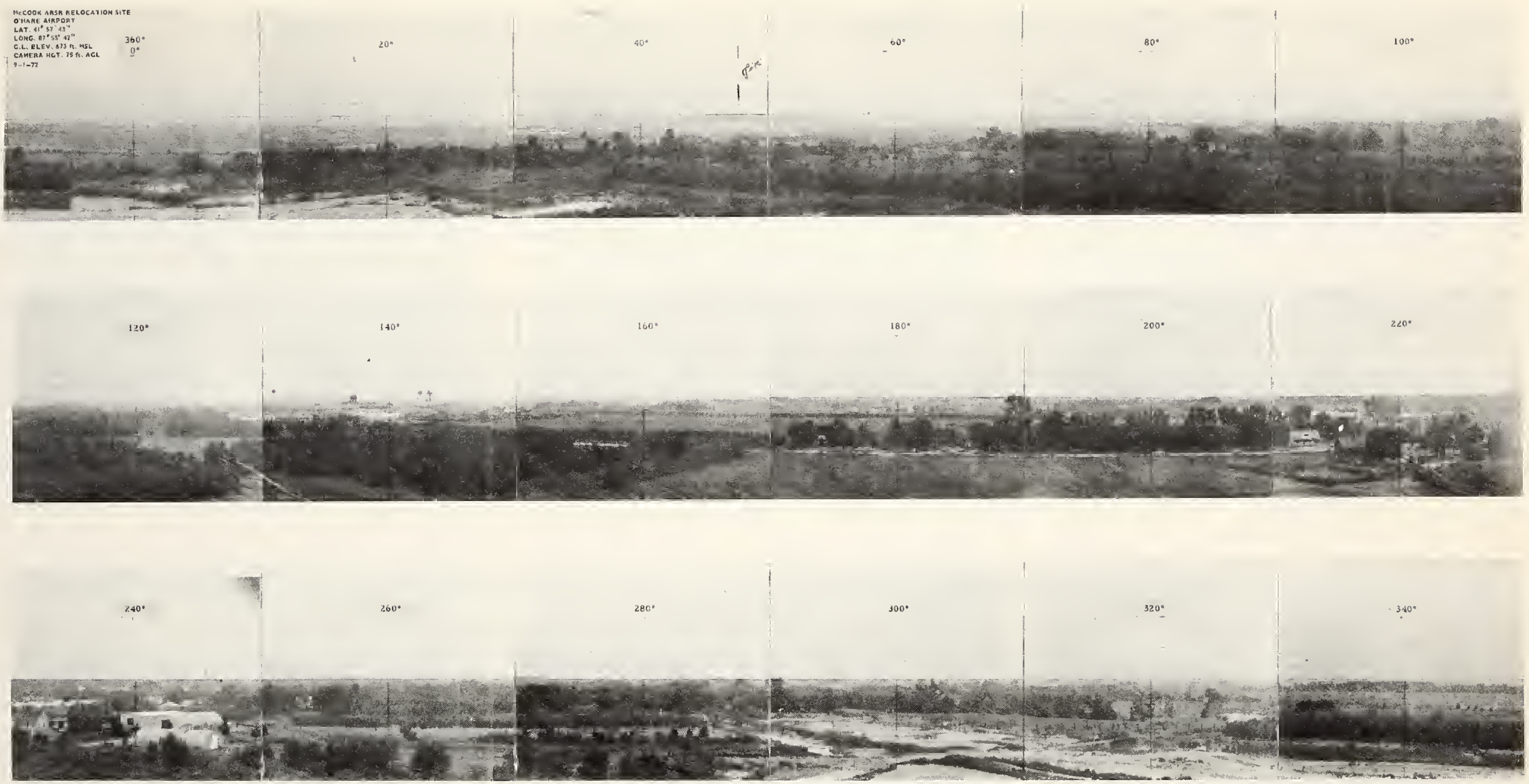


FIGURE 24. PANORAMIC VIEW OF TERRAIN SURROUNDING THE BEACON TEST SITE FROM A HEIGHT OF 75 FEET

The reason for the restricted range at the beacon test site was thought to be caused by the type of transmission line used on the omnidirectional antenna. Prior to the erection of the beacon test site, it was agreed that RG-197 (low-loss) cable would be used on both the directional and omnidirectional antennas. A normal enroute radar site uses 7/8-inch low-loss cable, and in some instances 1-5/8 inch low-loss cable, to feed the directional and omnidirectional antennas. RG-218U coaxial cable was used at the beacon test site. The RG-218U coaxial cable attenuates radar beacon frequencies the same as RG-17U coaxial cable, which is 4.4 dB per 100 feet. The loss afforded the radar beacon transmission by the 7/8 inch low-loss cable is nominally 1.5 dB per 100 feet while the loss afforded by the 1-5/8 inch low-loss cable is nominally .78 dB per 100 feet.

If the 1-5/8 inch low-loss cable were used to feed the omnidirectional antenna at the beacon test site, the range of the improved 3-pulse SLS system would have been extended by a factor of 1.52. This would have increased the minimum range of the improved 3-pulse SLS system from 53 nmi to 80 nmi and would have probably eliminated the reflected beacon replies that occurred south of the beacon test site. If some reflected replies remained after the transmission line cable was changed, then the power input to the omnidirectional antenna could be increased while the directional antenna input remained the same. Since both the directional and omnidirectional antenna radiation power would probably be increased by the changing of transmission lines to both antennas, the power input to the omnidirectional antenna will probably have to be increased by 3 dB to ensure that the reflected beacon replies south of the beacon test site were eliminated.

Some experimentation could also be performed on the fence along Irving Park Road. An additional fence could be installed on the beacon test site side of the original fence, and tilted as described in NAFEC Report No. NA-69-36 entitled "Experimentation and Analysis of Siting Criteria," dated September 1969, pages 85 through 89. Tilting the fence at approximately one-half the Brewster Angle would reflect the energy that strikes the fence into the ground where it would be absorbed.

The reflected beacon replies, that were recorded to the north of the beacon test site were confined to site azimuths between 355° and 15° (see Appendix). The range at which these reflected beacon replies occurred varied between 105 and 178 nmi which is far beyond the range of the improved 3-pulse SLS system. The reflecting surface that was thought to be responsible for producing these reflected replies was the airline hangars approximately 2 to 3 nmi to the north of the beacon test site.

Most of the reflected replies that occurred north of the beacon test site were caused by aircraft flying at site radials between 82° and 99°. One isolated case was recorded when an aircraft flying at 267° caused a reflected reply at 10°. Since most of these reflected replies are caused by aircraft flying in the vicinity of the 84° radial (see Appendix), a system could be

installed at the beacon test to increase the range of the improved 3-pulse SLS system in just this one sector. A NAFEC Data Report entitled "Investigation of Reflected Reply Problem at Trevose, Pennsylvania, Enroute Radar Beacon Site," dated January 1972, and associated with Project No. 031-241-01X, deals with this same problem that occurred at the Trevose, Pennsylvania, ARSR-2 Site. A horn antenna (similar to that shown in Figure 17) was used to provide increased gain for the omnidirectional antenna radiations in a certain sector where aircraft were flying when reflected replies were produced.

VERTICAL LOBING PROBLEMS. The vertical lobing problems that were encountered during the investigation of the beacon test site can be grouped into three areas. Vertical lobing caused a loss or narrowing of replies at site azimuths in the vicinity of the 13°, 84° and 170° radials. The vertical lobing that occurred, in the vicinity of the 170° radial, was rather minor and no further discussion will be addressed to this area.

The vertical lobing that caused a loss or narrowing of beacon replies in the northern sector and in the vicinity of the 84° radial was moderate in severity and was thought to be caused by reflections from the smooth terrain of the O'Hare Airport. The drainage lake on the O'Hare Airport was thought to play a major role in the loss of replies that occurred in the vicinity of the 84° radial.

Almost all of the loss or narrowing of beacon replies occurred at ranges beyond 100 nmi. This was due to: (1) a decrease in the intensity of the beacon signals with increased range, (2) an increase in the reflection coefficient of the terrain at the lower angles of propagation, and (3) an increase in the "apparent" smoothness of the terrain at angles closer to the horizon. If the transmission line that feeds the directional antenna were made of a low-loss 1-5/8 inch coaxial cable, fewer beacon replies would be lost or narrowed. At first it might seem that increasing the radiated power also increases the terrain reflection and nothing is gained. But, suppose a 1-volt signal was originally received in the aircraft direct from the site and a .4-volt signal was reflected from the terrain and then received in the aircraft. The resultant signal would be .6 volts when the direct and reflected signals were 180° out-of-phase. Now, suppose we increase the power output of the site, in fact, quadruple it. The signal received in the aircraft direct from the site increases to 2 volts (6 dB) and naturally the reflected signal is also doubled to .8 volts. But, now the resultant signal would be 1.2 volts when the direct and reflected signals were 180° out-of-phase. This means that increasing the power output of the directional antenna by 6 dB will result in doubling the range where the vertical lobing begins.

By changing the directional antenna cable from the RG-218U coaxial cable which was used during the test to a 1-5/8 inch low-loss coaxial cable, the effective power output of the directional antenna would be increased by more than 3 dB. This increase in effective power could extend the range of the beacon signals by a factor of 1.4. If nothing else, this should emphasize the necessity of using low-loss coaxial cable at enroute radar beacon sites and using this same type of cable for testing of prospective radar beacon sites.

Besides increasing the power output of the directional antenna, there is really very little that can be done to reduce the vertical lobing problem at any future O'Hare Airport enroute radar site. The terrain that is responsible for the vertical lobing problem is so extensive that only a directional antenna with a controlled vertical pattern would provide the total solution required.

FUTURE EXPANSION OF THE BEACON TEST SITE AREA.

At the present time, a storm water control and recreation preserve is planned for the area surrounding the beacon test site. Figure 25 shows a detailed plan of the lake, athletic field and picnic area that is expected to be developed. When the lake area is completely flooded, vertical lobing problems could start at site azimuths in the vicinity of the 300° radial where none exist at this time.

Figure 25 shows a U.S. Government Post Office Building approximately 1,000 feet southeast of the beacon test site. A two-floor structure has been proposed for this building. There should be no problem with this building if the structure is limited to just two floors. If a reflection problem were to develop in the future, due to the Post Office building, a screen of shrubs or short trees could be used to shield the building from the radar beacon site radiation.

The area designated on Figure 25 as "Plane Watch Hill" may also form an obstruction at site azimuths in the vicinity of the 260° radial. The development plan shows contour lines which seem to indicate that a rather large hill may be formed in the future, along with an observation area on the top of this hill. A detailed study of the elevations planned for "Plane Watch Hill" should be undertaken prior to making any firm decisions on the acceptability of the area as the site for a future O'Hare Airport enroute radar beacon site.

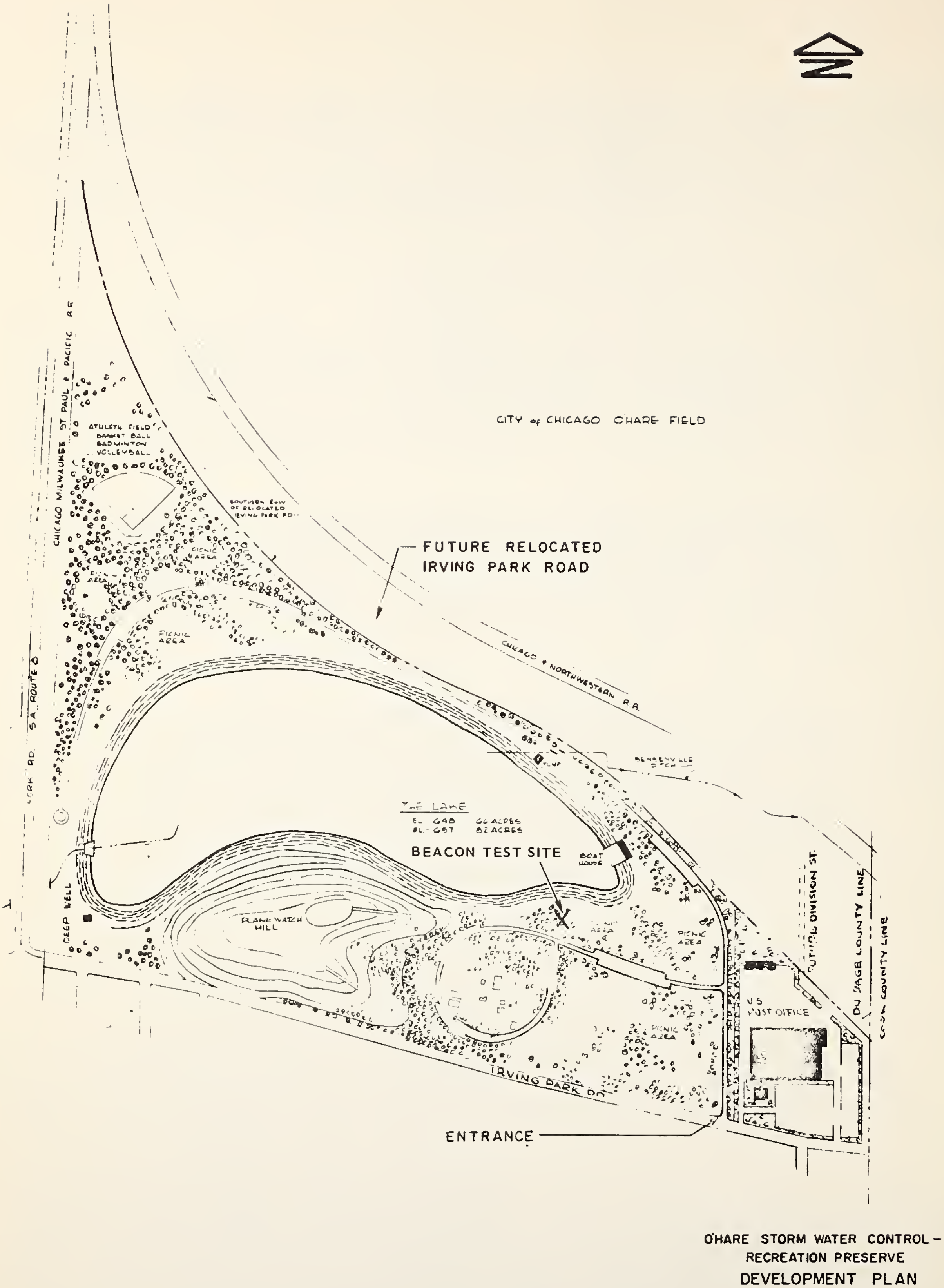


FIGURE 25. FUTURE DEVELOPMENT PLANNED FOR BEACON TEST SITE AREA

CONCLUSIONS

Based on the test data that was collected within the coverage area of the O'Hare Airport enroute radar beacon test site, it is concluded that:

1. The flat terrain and hangars of the adjacent airport make the O'Hare Airport enroute radar beacon test site something less than an ideal site from the standpoint of siting criteria.

2. Any future construction in the vicinity of the radar beacon site could limit the site coverage and increase the occurrence of reflected beacon replies.

3. Detailed coverage information can be obtained, for the siting of future radar beacon sites, through the use of temporary test facility similar to that used at the O'Hare Airport enroute radar beacon test site.

4. The existence and intensity of abnormalities, such as vertical lobing and reflected beacon replies, can be determined through the use of flight tests using the temporary test facility.

5. The use of coaxial transmission cable, other than that normally installed at radar beacon sites, required that an intuitive interpretation be performed on the test data in lieu of a direct one-to-one correlation.

APPENDIX

The following reflected beacon replies were noted during the analysis of the O'Hare Airport enroute radar beacon test site data using NAFEC Aircraft N-112.

2 October 1972

Frame	Aircraft Azimuth In Degrees	Reflection Azimuth In Degrees	Aircraft Range Nautical Miles	Reflection Range NMI
60	000	198	66	66
62	003	197	66	66
68	009	192	70	70
73	013	186	72	72
79	018	180	76	76
80	019	179	76	76
147	024	176	80	80
153	022	179	78	78
158	017	199	75	75
161	015	194	72	72
166	012	192	68	68
167	010	164	67	67
169	009	192	65	65
170	008	193	64	64
171	007	193	64	64
197	345	165	68	68
216	000	200	70	70
217	003	199	70	70
218	002	197	70	70
224	009	190	67	67
227	013	190	66	66
231-1	017	184	65	65
231-2	017	199	65	66
232	019	155	65	65
235-1	021	181	66	66
235-2	021	150	66	75
284	025	175	80	80
288	022	177	78	79
295	018	198	72	72
302	011	189	71	71
307	007	193	68	68
312	003	198	68	68
314	001	199	68	68
315	000	200	69	69
316	359	200	69	69
317	359	201	70	70
318	358	202	70	70
320	357	205	70	70

Aircraft flew over the site at 41,000 feet altitude to determine the overhead coverage of the site. The following azimuth and ranges were observed:

Lost radar beacon reply -- 344° azimuth at 9.5 nmi slant range.
Regained radar beacon reply -- 169° azimuth at 9.0 nmi slant range.

3 October 1972

Frame	Aircraft Azimuth In Degrees	Reflection Azimuth In Degrees	Aircraft Range Nautical Miles	Reflection Range nmi
124	085	013	178	178
188	090	006	116	116
189	090	007	115	115
190	090	007	114	114
394	083	015	105	105

Reflected replies obtained during the 150-nmi orbital flight test:

898	267	010	145	145
899	268	010	145	145
1258	099	355	145	145
1259	097	356	146	149
1260	099	355	146	149
1278	087	005	146	148
1280	087	001	145	147
1281	086	005	145	147
1291	082	010	145	147

4 October 1972

70	357	201	61	62
73	000	200	62	63
74	001	199	62	63
75	001	198	63	64
77	001	197	64	65
80	005	195	66	67
81	005	194	66	67
85	005	192	69	70
242	012	186	72	72
247	012	186	65	66
252	013	188	61	61
262-1	015	180	74	76
262-2	015	200	74	77
265	019	180	76	77
267	020	177	59	59
268	021	178	60	60
272	021	180	62	63
273	021	179	63	64

Frame	Aircraft Azimuth In Degrees	Reflection Azimuth In Degrees	Aircraft Range Nautical Miles	Reflection Range nmi
274	020	179	64	65
474	016	185	56	57
475	015	188	54	55
476	015	187	53	54
477	014	188	54	55
478	012	188	54	55
479	009	190	55	56
480	008	192	55	56
481	006	193	56	57
482	006	195	56	57
483	005	195	57	58
500	012	187	64	65

The following loss or narrowing of beacon replies were observed during the analysis of the O'Hare Airport Enroute Radar Beacon Test Site data using NAFEC Aircraft N-112:

3 October 1972

Frame	Azimuth In Degrees	Range In Nautical Miles	Comments
77	84	120	Normal Target
78	84	121	Weak Target
79	84	122	Very Weak Target
80	84	123	Normal Target
81	84	124	Weak Target
82	84	125	Very Weak Target
83	84	126	Normal Target
84	84	127	Weak Target
85	84		No Target Return
86	84	129	Normal Target
87	84	130	Very Weak Target
88	84	131	Normal Target
103	84	153	Normal Target
104	84	154	Weak Target
105	84		No Target Return
106	84	156	Very Weak Target
107	84		No Target Return
108	84	158	Weak Target
109	84	159	Normal Target
114	84	165	Normal Target
115	84	166	Weak Target
116	84		No Target Return
117	84	168	Very Weak Target
118	84	169	Normal Target

Frame	Azimuth In Degrees	Range In Nautical Miles	Comments
119	84		No Target Return
120	84	171	Weak Target
121	84	173	Weak Target
122	84		No Target Return
123	84	176	Weak Target
124	84	177	Normal Target
291	77	114	Normal Target
292	77		No Target Return
293	77	115	Normal Target
299	77	122	Normal Target
300	77		No Target Return
301	77	125	Normal Target
307	77	131	Normal Target
308	77	132	Weak Target
309	77	133	Weak Target
310	77	134	Normal Target
455	89	132	Normal Target
456	89	133	Very Weak Target
457	89	134	Normal Target
458	89	135	Very Weak Target
459	89	136	Normal Target
632	17	150	Normal Target
633	16	150	Weak Target
634	16		No Target Return
635	15	149	Normal Target
669	001	148	Normal Target
670	000	148	Weak Target
671	359	148	Weak Target
672	358	148	Normal Target
675	357.5	148	Normal Target
676	357	148	Very Weak Target
677	356.5	148	Weak Target
678	356	148	Very Weak Target
679	355.5	148	Weak Target
680	355	148	Normal Target
713	341	148	Normal Target
714	340.5	148	Weak Target
715	340	148	Normal Target

Frame	Azimuth In Degrees	Range In Nautical Miles	Comments
1103	170.5	146	Normal Target
1104	170	146	Weak Target
1105	169.5	146	Normal Target
1106	169	146	Weak Target
1107	168.5	146	Normal Target
4 October 1972 (Morning)			
116	10	101	Normal Target
117	10	102	Weak Target
118	10	103	Weak Target
119	10	104	Normal Target
120	10	105	Normal Target
121	10	106	Normal Target
122	10		No Target Return
123	10		No Target Return
124	10	109	Normal Target
125	10	110	Normal Target
126	10	111	Weak Target
127	10	112	Weak Target
128	10	113	Normal Target
129	10	114	Weak Target
130	10	115	Normal Target
137	10	123	Normal Target
138	10	124	Weak Target
139	10		No Target Return
140	10	126	Very Weak Target
141	10	127	Very Weak Target
142	10		No Target Return
143	10	129	Very Weak Target
144	10	130	Weak Target
145	10	131	Weak Target
146	10	132	Normal Target
153	10	140	Normal Target
154	10		No Target Return
155	10		No Target Return
156	10	143	Weak Target
175	13	133	Normal Target
176	13	132	Weak Target
177	13	131	Normal Target
184	13	126	Normal Target
185	13		No Target Return
186	13	124	Normal Target

Frame	Azimuth In Degrees	Range In Nautical Miles	Comments
211	13	101	Normal Target
212	13	100	Very Weak Target
213	13	99	Very Weak Target
214	13	98	Normal Target
306	16	98	Normal Target
307	16		No Target Return
308	16	101	Weak Target
309	16	102	Normal Target
310	16	103	Very Weak Target
311	16	104	Normal Target
317	16	110	Normal Target
318	16		No Target Return
319	16		No Target Return
320	16	113	Normal Target
322	16	115	Normal Target
323	16	116	Weak Target
324	16	117	Weak Target
325	16	118	Normal Target
330	16	123	Normal Target
331	16	124	Very Weak Target
332	16	125	Weak Target
333	16	126	Weak Target
334	16	127	Very Weak Target
335	16	128	Very Weak Target
336	16	129	Weak Target
337	16		No Target Return
338	16	131	Normal Target
347	16	142	Normal Target
348	16	143	Weak Target
349	16		No Target Return
350	16	145	Weak Target
351	16	146	Normal Target
353	16	148	Normal Target
354	16	149	Weak Target
355	16		No Target Return
356	16		No Target Return
357	16	152	Weak Target
358	16	153	Normal Target
417	16	112	Normal Target
418	16	111	Very Weak Target
419	16	110	Very Weak Target
420	16	109	Normal Target

Frame	Azimuth In Degrees	Range In Nautical Miles	Comments
426	16	104	Normal Target
427	16	103	Weak Target
428	16		No Target Return
429	16	101	Normal Target
430	16	100	Normal Target
431	16		No Target Return
432	16	98	Normal Target

4 October 1972 (Afternoon)

Frame	Azimuth In Degrees	Range In Nautical Miles	Comments
256	71	113	Normal Target
257	71		No Target Return
258	71	115	Very Weak Target
259	71	116	Weak Target
260	71		No Target Return
261	71	119	Normal Target
267	71	125	Normal Target
268	71	126	Very Weak Target
269	71	127	Normal Target
273	71	131	Normal Target
274	71	132	Weak Target
275	71		No Target Return
276	71		No Target Return
277	71	135	Weak Target
278	71	136	Normal Target
357	60	73	Normal Target
358	60	72	Weak Target
359	60	71	Weak Target
360	60	70	Normal Target
387	71	63	Normal Target
388	71	64	Weak Target
389	71	65	Very Weak Target
390	71	66	Broken Target
391	71	67	Normal Target
426	71	105	Normal Target
427	71		No Target Return
428	71		No Target Return
429	71		No Target Return
430	71		No Target Return
431	71		No Target Return
432	71	110	Normal Target

Frame	Azimuth In Degrees	Range In Nautical Miles	Comments
434	71	112	Normal Target
435	71	113	Weak Target
436	71	114.5	Weak Target
437	71	116	Normal Target
438	71	117.5	Weak Target
439	71	119	Weak Target
440	71	120	Normal Target
445	71	125	Normal Target
446	71	126	Weak Target
447	71		No Target Return
448	71	128	Normal Target
450	71	130	Normal Target
451	71	131	Weak Target
452	71		No Target Return
453	71		No Target Return
454	71	135	Weak Target
455	71	136	Weak Target
456	71	137	Normal Target
5 October 1972			
203	162	70	Normal Target
204	162	71	Weak Target
205	162	72	Weak Target
206	162	73	Normal Target
526	170	81	Normal Target
527	170	80	Weak Target
528	170	79	Very Weak Target
529	170	78	Normal Target
530	170	77	Weak Target
531	170	76	Normal Target
1231	25	143	Normal Target
1232	23	143	Weak Target
1233			No Target Return
1234			No Target Return
1235			No Target Return
1236			No Target Return
1237			No Target Return
1238			No Target Return
1239			No Target Return
1240	20	142	Normal Target

Frame	Azimuth In Degrees	Range In Nautical Miles	Comments
1247	17	142	Normal Target
1248			No Target Return
1249			No Target Return
1250			No Target Return
1251	15	142	Normal Target
1266	10	142	Normal Target
1267	9	142	Weak Target
1268	8	142	Weak Target
1269			No Target Return
1270			No Target Return
1271	6	142	Normal Target